Commentary

SALES TALK

SCIENCE and technology are at one end of the industrial conveyer belt and advertising is at the other.   There is little love lost between them. ' Sales talk ' is a term of abuse among scientists and the ' salesman ' is regarded as a close relative of the spiv.   For their part, advertisers regard a scientist as a boffin to whom it is fashionable to doff the cap in public and curse in committee.   The conflicting attitudes are, of course, ridiculous as extremes often are.   The scientist has a direct responsibility to put his work across and in these days when his needs of financial support can often only be described as 'imperial', it ill-becomes him to sneer in ignorance at those whose job it is to direct public taste and demand.   Just as it ill-becomes the advertiser to deride his future.

The advertising industry aims at each of us and we all have our own views so that it is perhaps not surprising if even the preparation of simple statistics presents problems. The Advertising Association perform a real service by publishing at intervals a digest[1] though there are strange omissions. There is no comment on the place and cost of ' packaging '; obviously most goods require some form of packaging but this is usually used as a direct form of advertisement.   There are no remarks on the cost of establishing and maintaining scientific and technical standards.   Doubtless the cost is modest but the need and use of standards in the world of competitive sales are obvious.

In round terms we are spending per year in this country something of the order of £350 millions on advertising which ' now costs the consumer the equivalent of the cost of two-thirds of our educational service and about four times the cost or our police force '[2].   This expenditure is about two per cent of the net national income and, as a proportion of the national income is roughly 60 per cent of the corresponding expenditure in the United States; it is lower in Europe and Japan, though the figure for Belgium—0·5 per cent of the national income in 1956—seems very peculiar[1].

Some of the facts which emerge are fascinating, some strange, some are surely significant.   Thus the cost per column inch is lower in the national morning papers than it is in the London evening papers but it is higher in the provincial morning than it is in the provincial evening papers. Expendi-ture by national advertisers in the provincial press rose from £8·5 millions in 1952 to about £17 millions in 1956. Twenty years ago almost half, 41 per cent, of the United States expenditure was in morning and evening newspapers; this has fallen—in this country it is rising—until it seems likely they will coincide at about 30 per cent. Knowing the beautiful and expensive layout of American trade and technical journals, it is suprising to discover that they spend a materially smaller percentage in this way than is spent in this country.

Most of the emotional heat generated by advertising is obviously related to its aims, real or imputed but even the most virulent critic cannot, realistically, class it all as waste.   The same critic pays half, and in the provinces more like a third, of the cost of production of his newspaper, the rest is carried by advertising revenue.   Independent Television is the obvious example of a public service paid by advertising.   Taking reliable estimates of figures[3], the General Director of the Institute of Economic Affairs has divided the costs of advertising into three categories[4]—the figures given[3] are based on 1957 estimates—(i) trade information (£106m.), (ii) public benefit (£134m.) and (iii) net cost (£125m.); in this case the total is £365m.   There are no doubt many opinions as to the correct proportions which should be assigned under such headings.   Nevertheless it should always be remembered that there are such headings and that the whole, considerable figure should not simply be classed as ' advertising, pure and simple ', whatever that may mean.

The figures quoted for advertising are figures of expenditure within this country.   And the scientist and the advertiser are at opposite ends of the conveyer belt.   The latest, round figures for expenditure on research in this country[5], an expenditure which covers *all* activities, is £300 millions, of which less than £70 million is spent by private industry for its own purposes.   This is our future well-being.   Set in this context we do seem to spend a lot among ourselves in seeking how to keep up with the Joneses !

[1] *Advertising Expenditure, 1950,* London: Advertising Association, 1958
[2] *Hansard, 595,* 1542 (STONEHOUSE, J. Debate on November 21st, 1958)
[3] ABRAMS, M. *Financial Times* (April 23rd, 1958)
[4] HARRIS, R. Advertising, a Cost or a Contribution to the Nation *Esso Magazine* 7 (Autumn, 1958) 5
[5] Report of the Advisory Council on Scientific Policy, 1956/7

WEATHER FORECASTING

Part II—Present and Future

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The first part of this article, published in the December issue of **RESEARCH**, outlined the history of weather forecasting. The second part deals with the present methods used and the developments that are likely to take place in the near future.

AS MENTIONED in the first part of this article, the synoptic method of forecasting is to represent the physical properties of the atmosphere on charts and diagrams in such a way as to provide schematic pictures of the atmosphere itself at successive intervals of time, thereby facilitating a study of the evolution of weather systems as revealed by the sequence and then an extrapolation into the future of the observed trends.

Organization

In developing a forecasting organization, many factors (including cost!) have to be taken into consideration. For example, it has been necessary to determine the most suitable network of stations: according to the density so a particular set of meteorological phenomena are revealed, varying from rain belts a few miles wide to depressions or areas of low or high pressure which may cover hundreds of miles. Again, according to the frequency of observations so will the life-history become apparent of phenomena such as an individual thunderstorm lasting perhaps for less than an hour or a depression which may have a duration of two or three days. The scale and area of the chart must also be chosen to suit the phenomena which experience has shown are important in forecasting. Indeed, an essential part of chart analysis is the assessment of how representative are the individual observations of the disturbances which are being studied. Obviously it is important that the observations must be consistent; hence the need for a standard exposure at the observation sites.

Every country now maintains a network of observing stations and most countries are members of the World Meteorological Organization which is one of the Specialized Agencies of the United Nations. By international agreement, observations are made by standard methods and at standard hours. The main standard times for surface synoptic observations are 0000, 0600, 1200 and 1800 G.M.T.; the intermediate times are 0300, 0900, 1500 and 2100 G.M.T. For upper air synoptic observations the four standard times are 0000, 0600, 1200 and 1800 G.M.T. The World Meteorological Organization regulations in regard to the network of observing stations for synoptic purposes are that land stations should be spaced at intervals not exceeding 150 km for surface observations and not exceeding 300 km for upper air observations. Each member is expected to make arrangements for ships' observations, the aim being to secure a density of reports from ships of all nationalities, over all ocean areas traversed by shipping, of at least one per 500 kilometres for each main standard time of observation. In addition, by international agreement, ocean weather ships are maintained at fixed locations in the Atlantic and Pacific; these ships provide upper air as well as surface observations.

Synoptic surface reports consist of observations of the present and past weather, wind direction and speed, amount, type and height of cloud, visibility, temperature, humidity, pressure, the character and amount of pressure change, plus, at specified times, extremes of temperature, amount of precipitation and state of ground; in addition, ships report sea temperature, wave direction, period and height, as well as their course and speed. Upper air synoptic reports embrace temperature, pressure, humidity, wind speed and direction; in some countries, as in the United Kingdom, these reports are supplemented by data provided by meteorological reconnaissance flights.

Communications: Codes

In each country, the observing stations send in their reports to a national collecting centre. These centres then send collective messages by landline or radio to sub-continental and continental centres which in turn broadcast selected data for the benefit of all concerned. The necessary arrangements are highly complicated. For example, Europe is divided into four sub-continental regions, in each of which there is a powerful transmitter which repeats the various national transmissions comprised within the region. One of these is operated from
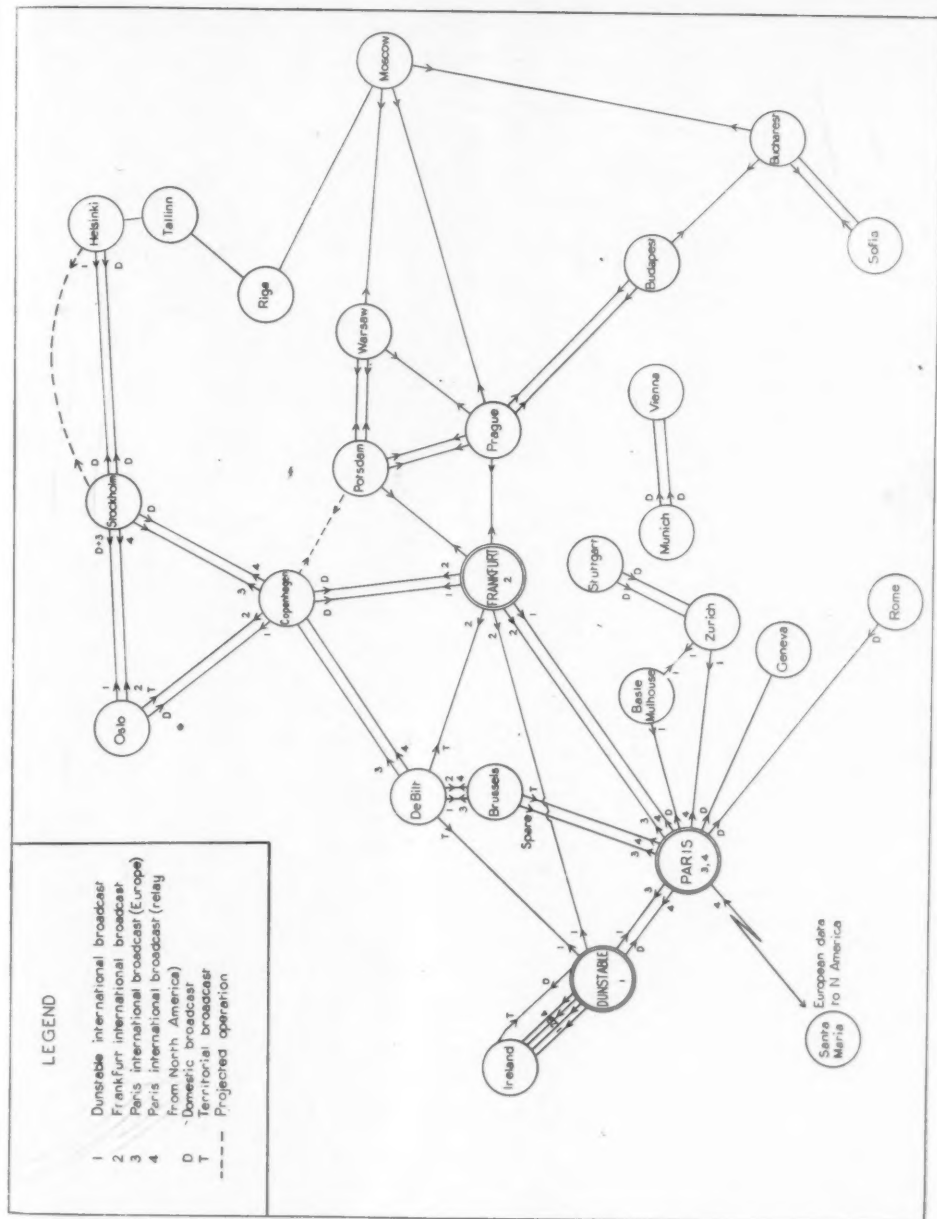
Figure 1. International meteorological landline teleprinter circuits in Europe

Dunstable and sends out data from the British Isles, Norway, Sweden, Iceland, Greenland, *etc*. The other three are at Paris, Rome and Moscow. Dunstable also broadcasts a selection of reports from all over Europe so that the smaller services can obtain the essential weather reports for Europe

Figure 2. Coded weather report

and the eastern Atlantic on only one receiver and are thus saved the trouble of listening in to the subcontinental or national transmissions. In addition, there are special arrangements for the exchange of reports between Europe and North America, and special wireless transmissions to meet the needs of aviation and shipping. As will be seen from *Figure 1* mainly landlines are used for the transmission of reports in Europe.

In the British Isles, special teleprinter lines radiate from the Central Forecasting Office to local centres, from which, in their turn, more teleprinter lines radiate to the individual stations. The whole area is thus covered with a network of lines by the aid of which all the coded reports of observations made at a given hour can be concentrated at the Central Forecasting Office within a very few minutes. Also at this office there are automatic teleprinter broadcasting facilities, so that the messages received can be simultaneously transmitted at high speed to all the ' out station ' forecasting offices and to certain Continental centres. All the incoming reports, British and also a selection of near-Continental data, are disposed of within half an hour. Radio transmissions (in Morse code) are used to exchange information with more distant areas.

As it would be too cumbersome for each reporting station to send its observations in plain language, compact codes have been designed by the World Meteorological Organization. The codes consist of groups of five figures arranged in an agreed sequence so that the figures relating to each item of information are always found in the same place. A specimen surface report is shown in *Figure 2*.

Finally, there is the problem of presenting on the surface weather map the many observations embodied in a synoptic report. This is solved by plotting the information in accordance with an internationally agreed ' station model ' (*Figure 3*), *i.e.*, a semipictorial form whereby the weather report from each station is represented by a small group of symbols and figures arranged around the position of the reporting station on the map. When plotted on a synoptic chart the coded weather report shown in *Figure 2* would appear as in *Figure 3*.

Forecasting Procedures

It is not possible in the space available to give a detailed account of the procedures used in weather analysis and forecasting. For this the interested reader is advised to consult one of the standard textbooks on the subject. Mention has already been made in the first part of this article of the meteorologist's approach to the problem of forecasting. This may be regarded as consisting of two parts, diagnosis and prognosis. Diagnosis means determining the evolution of the field distributions of the physical properties of the atmosphere. Prognosis involves the extrapolation into the future of the general synoptic evolution plus the superposition of a fine structure in space and time; this fine structure calls for the consideration of local physical factors, such as the effect of smoke pollution on visibility, and the use of statistics such as known extremes and variations of a particular element.

At the Central Forecasting Office the following charts are plotted every day

Surface charts

1:3 m	British Isles and adjacent Continent	hourly
1:10 m	Eastern North America–North Atlantic–Europe	3-hourly
1:30 m	Northern Hemisphere circumpolar	Twice daily

Upper air charts

1:10 m	Eastern North America–North Atlantic–Europe (700, 500, 300, 200, 100 millibars)	Twice daily
1:10 m	Eastern North America–North Atlantic–Europe (1000/500 millibar thickness)	Twice daily
1:30 m	Northern Hemisphere circumpolar (500 millibar)	Once daily
1:30 m	Northern Hemisphere circumpolar (1000/500 millibar thickness)	Twice daily

In addition, diagrams are drawn of the upper air temperature and humidity distribution at each of the upper air stations in the British Isles plus the data

from the ocean weather ships and a number of Continental stations situated within the main airstreams expected to affect the British Isles.

On the surface charts the positions of fronts are entered and the associated cloud and rain areas are carefully noted. The forecaster's first step is to assess the movement and development within the next 24 hours of the main pressure systems and frontal systems. In actual practice, he prepares a surface chart called a ' prebaratic ' showing the expected positions of isobars and fronts at the end of the 24-hour period and an upper air chart called a ' prontour ' chart showing the expected position of the 500 millibar contours also at the end of the 24-hour period. Given the prebaratic and prontour charts, the next task is to determine the weather conditions, winds aloft, and all the various bits of information required by those who demand service from the forecaster. Only those who have had experience of forecasting can realize the difficulties of meeting these demands to the entire satisfaction of the customer!

Forecasting Services

Forecasts normally cover a period up to 24 or 30 hours with an ' outlook ' for the succeeding 24 hours; only occasionally can the period be longer. But in spite of the forecaster's limited ability to ' produce the goods', the demand for special forecasts, even though available for only short periods ahead, continues to be insistent and to increase. There is also an unsatisfied demand for forecasts for a week or month ahead! For the public, forecasts supplied by the Meteorological Office are issued by the B.B.C. both on sound and television and also by the commercial television companies; forecasts for shipping and fishermen are also provided through

Figure 3. The plotting model and plotted weather report

the B.B.C. and other broadcasts for shipping are sent out from Post Office transmitters.

Forecasts for all land areas of the British Isles are issued to press agencies and newspapers three times daily. In London there is a ' regional ' forecasting office which may be consulted by telephone and which arranges for the supply of forecasts for the London area and southeast England. This office

also provides through the General Post Office an automatic telephone weather service covering

    (*i*) the London area,
    (*ii*) the Essex coast,
    (*iii*) the Kent coast and
    (*iv*) the Sussex coast.

In addition to these services for the civil community there is, of course, a large organization for meeting the specialized requirements of aviation, both civil and military.

Some of the out-station offices in this organization also provide a public forecast service either through direct consultation on the telephone or through an automatic telephone system. The latter service is now in operation for Birmingham, Liverpool and Manchester area, Cardiff area, Belfast, Glasgow and Edinburgh. The Meteorological Office is also prepared to supply special forecasts to any organization or individual; all requests receive careful attention.

Forecasting Research

To satisfy the demand for more accurate and longer period forecasts, and in view of the enormous economic value of accurate forecasts for as long a period as possible, most meteorological services are devoting part of their resources to forecasting research. This research must of necessity cover a very broad field and embrace synoptic, dynamic and physical aspects and also instrumental development. To meet these requirements, the Meteorological Office has a Director for Research, as well as a Director for Services, both under the Director General. On the Research side there are a number of divisions each of which deals with a particular set of problems in a meteorological research programme drawn up by a Meteorological Research Committee; all the items have a direct or indirect bearing on the problem of forecasting.

The synoptic and dynamical research divisions are concerned with the development of forecasting techniques generally (including medium and long range forecasting) and, in particular, with the improvement of techniques for the forecasting of fog, cloud and precipitation and the effect of topography; of particular interest, is the study by the dynamical research division of numerical forecasting with electronic computing.

The climatological research division is concerned with the study of the general circulation of the atmosphere—important to forecasting as background knowledge. The atmospheric physics division is responsible for research in the physics and the chemistry of the atmosphere, especially cloud and precipitation physics which are of vital importance in forecasting. Then there is an instrumental development division which has the task of designing and developing meteorological equipment with the
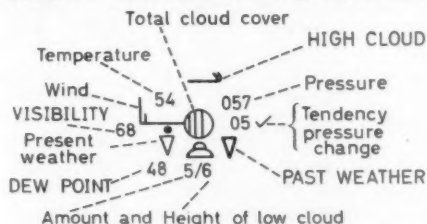
object of improving and extending the basic data which the forecaster has to use.

Improvements in the ability of the meteorologist to predict the weather a few days ahead, and even a small advance in his ability to predict the weather a week or month ahead, may make a big difference in the real value of the meteorological service. At present, hopes are based on (*i*) the development of statistical methods for long range forecasts—this is still largely experimental—and (*ii*) objective and mathematical methods for short range prediction.

Numerical Weather Prediction

The laws of motion of a real system are incredibly complicated and it is usual to invent a model system which has the essential properties that it is desired to examine in the real system and for which simple ' laws of motion ' can be written down. More than one model may be necessary for different aspects of the same physical system, *e.g.*, for the thermo-dynamic properties of a gas a model composed of a large number of moving particles is considered, while for hydrodynamical properties a model which is a continuous fluid is considered. The validity of the model is tested by inserting into the equations describing it some measurement made on the real system, and then comparing the prediction using the model with actually what happens in the real system.

Nearly forty years ago, L. F. RICHARDSON[1] advanced the idea of dealing with the problem of forecasting on the basis of fundamental equations. He used the Newtonian equations of motion, appropriate to a fluid under the action of the forces of pressure and gravity, and the equation of continuity of mass. As the equations are too complicated for general solution by direct integration, he obtained a solution by introducing finite changes due to the effect of the various forces in a finite time, assigning approximate values to the various forces for the interval. But the idea of using a model, containing both hydrodynamical and thermodynamical theories which would satisfactorily resemble the atmosphere in so far as its motions are concerned, could not be developed because of the difficulty of actually solving the equations and because of lack of adequate data to determine the actual state of the atmosphere. Over the years there has been a steady increase in the amount of basic data available to the forecaster, both for the surface and upper air, so the second difficulty has been largely overcome.

With the development of high speed computers, it is now hoped that the first difficulty may also be sur-mounted as they make possible the computations of a kind necessary to provide ' prebaratic ' and ' prontour ' charts. Indeed, with the aid of realistic models and adequate data, there is now no doubt that it is possible to integrate the relevant equations through time and obtain predicted pressure distri-butions which are similar to the distributions which actually occur after a period of at least 24 hours.

So far only the weather systems on a synoptic scale are included in numerical predictions and it is still necessary to fit the ' weather ' to the predicted pressure patterns. In fact, there are some thorny problems and the results obtained by using the electronic computer which is being installed at the Meteorological Office are awaited with interest. A simple account of numerical forecasting has recently been given by E. KNIGHTING[2].

Further Outlook

It must be realized that it is not possible to reduce the entire complex physical phenomena of the atmosphere–earth–ocean system to laboratory size and subject them to detailed analysis. Indeed, ability to observe all the elements that go to make this complicated, many variable, system is still very limited and to describe it in all its facets at any given incident of time is impracticable. There are scales of atmospheric motion, varying from the small scale turbulence caused by friction or surface roughness as revealed by the small eddies in the smoke from a factory chimney, and larger scale turbulence caused by hills or local uneven heat-ing of the ground as revealed by orographic clouds or dust devils, to the familiar patterns which are associated with the general circulation of the atmo-sphere such as depressions, anticyclones and thence to the huge global patterns of vorticity miles above the ground.

The spectrum of atmospheric motion, the inter-change of a mainly ' zonal ' or latitudinal circulation with a meridional circulation, the persistence of a particular pattern—or the rather sudden changes of predominant pattern at certain times of the year and not another, and the variation in the frequency of patterns from year to year—all these are somehow linked to the uneven heating of the atmosphere and the effect of gravity. Maybe the data which are being obtained during the International Geophysical Year will bring us nearer to an explanation. Mean-while, weather forecasting provides a means of testing our understanding of the atmosphere; but to the extent that we cannot observe and elucidate atmospheric processes, so our forecasts of the future consequences of these processes will continue to be imperfect.

References

[1] RICHARDSON, L. F. *Weather Prediction by Numerical Process* Cambridge: Cambridge University Press, 1922
[2] KNIGHTING, E. *Weather* 2 (1958) 39

SYNTHETIC RUBBERS IN THE POST-WAR WORLD

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Starting with a description of the six types of synthetic rubber available at the end of the second World War, the author traces the developments which have since occurred, and concludes with details of some new types which have made their appearance in the intervening years.

SOME SIX different types of synthetic rubber were being produced at the end of the second World War, chiefly in the United States and Germany and to a lesser extent in Russia. By far the largest production and consumption was of the general purpose butadiene–styrene copolymer called *GR–S* in the United States and *Buna S* in Germany. Although not as abrasion resistant as natural rubber, it was a passable substitute under wartime conditions for tyres, belts, and general mechanical rubber goods. Next in quantity came the production of the more expensive oil-resistant rubbers, *Neoprene* (*GR–M*) and butadiene–acrylonitrile (*GR–A, Buna N*). Several grades of the former were available, differing slightly in degree of polymerization and chain branching, and three grades of the latter corresponding to different levels of acrylonitrile content.
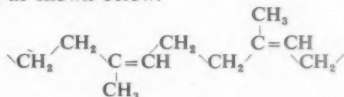
Another type of oil-resistant rubber, the poly-sulphide or thioplast (*GR–P, Perduren*), was also produced in a variety of grades corresponding to different starting products and different physical properties. The copolymer of *iso*butylene and isoprene known as *GR–I* or butyl rubber was prepared in the United States for such products as inner tubes and air bags where its low permeability to gases and good heat resistance were invaluable. The German polymer chemists, on the other hand, seem to have concentrated their efforts on the development of a totally different type of polymer, the polyurethane, which gave a highly abrasion resistant vulcanizate: this rubber, *Vulkollan*, made its appearance shortly before the end of the war.

Since the end of the war developments have been largely along the same lines, using similar monomers and making small alterations to the polymers. In addition there have been some chemical modifications of natural rubber to produce special polymers as well as syntheses, on the pilot plant scale, of natural rubber itself. It is proposed to describe the latter products first, then to consider each of the types of synthetic rubber mentioned above and show in what ways the new polymers are different from them. Finally a description will be given of some other new polymers which do not show any similarities with the synthetic rubbers already described.

'Synthetic Natural Rubber'

Natural rubber is a polyisoprene, predominantly of 1:4 addition with the *cis* configuration at the double bonds, as shown below.

$$\overset{CH_2}{\underset{CH_2}{\diagdown}} C=CH \overset{CH_2}{\underset{CH_2}{\diagdown}} \overset{CH_3}{\underset{C}{|}} C=CH \overset{}{\underset{CH_2}{\diagdown}}$$

Until recently no synthetic natural rubber was possible because the formation of a polymer in which all the double bonds had mainly the same configuration presented an insurmountable difficulty. It has now been possible by heterogeneous catalysis to produce polymers of known stereo-configuration. The catalysts are active metals or metallo-organic compounds and it seems that the monomer combines with the metallo-organic compound to produce a polarized molecule which adopts, when adsorbed on to the surface of the catalyst, a fixed configuration according to the degree of polarization and the precise nature of the catalyst. *cis*-Polyisoprenes prepared in this way have been found to possess all the physical properties of natural rubber, and to show very similar x-ray photographs.

The isoprene monomer must be very pure and, at present, this makes the commercial success of synthetic natural rubber doubtful under normal conditions. The chief interest is in its strategic significance; countries which can produce such ' synthetic natural rubber ' could be independent of the Malaya rubber plantations. A recent news item suggests that the Soviet Union is already producing synthetic natural rubber in amounts of several

million pounds a year, although no details are given of the initial raw materials or the method used for manufacturing the isoprene.

Figure 1. The areas in the vicinity of the rivets of this steel water pipeline, which serves the San Fernando hydroelectric plant, were first coated with Neoprene primer followed by a sprayed Neoprene coating; no leaks have occurred since 1955 (by courtesy of Du Pont)

Derivatives of Natural Rubber

The action of concentrated sulphuric acid or other strong acids on natural rubber has been known for many years: two units of isoprene form a six-membered ring in a reaction which is thought to be as follows

$$-CH_2C=CHCH_2 \overset{CH_3}{CH_2C}=CHCH_2 \longrightarrow$$
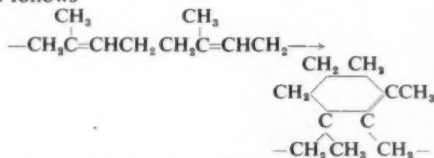
For a long time this ' cyclized ' rubber was used only in rubber-to-metal bonding and as a thickening medium for printing inks, giving them a hard glossy finish. Recently it has been found that the reaction can be carried out in the latex phase and the product used as an organic stiffener in ' resin–rubber ' shoe soling, in rubbers for printing machinery, and also for the production of rigid, non-brittle mouldings.

The natural rubber latex is first stabilized by means of a cationic soap and sulphuric acid is added. After this cyclized latex has been allowed to stand for a few hours at 100°C, it is added to fresh latex containing an anionic stabilizer. Mutual coagulation occurs, and the coagulum is washed on a mill and marketed as a cyclized rubber masterbatch.

Another chemical reaction which can take place in the latex phase is that leading to the formation of graft polymers. Monomers such as methyl meth-

acrylate are polymerized in the presence of natural rubber latex, when short polymethylmethacrylate chains are grown on the rubber molecules. The product is coagulated with calcium chloride solution, washed, and worked into sheets. *Heveaplus MG*, which is of this type has been used as a stiffening agent for normal rubber compounds; it imparts good resistance to flex-cracking and cut growth with low dynamic modulus and hysteresis properties. It is also used for making rigid shock proof mouldings, which can be sterilized by heat.

Butadiene–Styrene Copolymers

During the war the United States government permitted only one general purpose rubber to be manufactured, and no deviation from the conditions of polymerization were allowed. After the war, when natural rubber was available once more, a certain amount of latitude was permitted and experiments were made to find a better polymerization recipe than the one previously used. The reaction between the hydroperoxide and a ferrous salt, resulting in the production of free radicals, appeared promising

$$ROOH + Fe^{2+} \rightarrow Fe^{3+} + OH^- + RO-$$

and it was found that with this system the temperature of polymerization could be reduced from 50°C
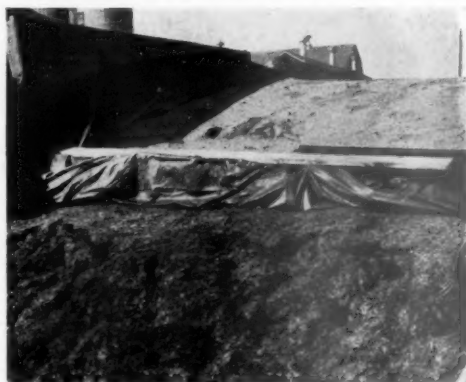

Figure 2. Silage in horizontal silo bunker, partially opened for feeding, is protected from spoilage by Neoprene-coated nylon fabric. It has been found to be the most effective of several materials which were tested at the U.S. Department of Agriculture's Research Centre, Beltsville, Md. (by courtesy of Du Pont)

to 5°C. The ferric salt can be reduced to the ferrous state continuously by the addition of glucose to the reaction mixture.

The product of the new polymerization technique has a higher molecular weight than the previous polymer, and in consequence better tensile strength

and abrasion resistance when vulcanized. Polymers of such a high molecular weight have been developed by this process that they are extremely difficult to process and a technique was evolved whereby oil is added to the latex phase before coagulation. These oil-extended rubbers are much easier to process, but have lower tensile strength and tear resistance than the corresponding 'cold' polymers. However, the abrasion resistance is comparable, the tear resistance at elevated temperatures is improved, as are the heat build-up and resistance to cracking when flexed.

It is convenient to include here the high styrene resins. These copolymers of butadiene and styrene, containing about 85 per cent of the latter component are used as stiffening agents for natural and synthetic rubbers in the same way as is cyclized natural rubber. The greatest consumption by far of these resins is in shoe soling of the resin–rubber and microcellular types. Compounded with a butadiene–styrene or natural rubber and a semi-reinforcing white filler, it is possible to obtain soles which are not black in colour and have many times the abrasion resistance of leather, although care must be taken in compounding to avoid a product which is thermoplastic and will flow during service.

Neoprenes and Hypalon

Many synthetic rubbers have been developed from the general purpose *Neoprene GN* which was produced during the war; some examples of the varied applications are shown in *Figures 1* and *2*. It was a copolymer of chloroprene and sulphur, in which chains of chloroprene units were joined together with polysulphide links ($\cdots$ S–S–S–S $\cdots$), there being about one sulphur atom to every hundred units of chloroprene

$$\cdots CH_2 \overset{Cl}{\underset{|}{C}} = CHCH_2 CH_2 \overset{Cl}{\underset{|}{C}} = CHCH_2 \cdots$$
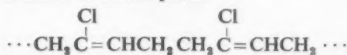
Neoprene GN has a tendency to crystallize both in the uncured state and when vulcanized. A later development, *Neoprene GRT*, is formed by the copolymerization of a small amount of styrene with the chloroprene and sulphur. In this way the regularity of the polychloroprene chain is broken and the tendency to crystallization reduced.

Neoprene W represents a fundamental change in the polymerization process by which a more uniform structure is produced: no sulphur or vulcanization accelerators are present. It possesses improved storage stability and better processing properties than the GN and GRT varieties. By copolymerizing chloroprene with a small quantity of styrene under the same conditions as for Neoprene W, a polymer resistant to crystallization is produced: this is named *Neoprene WRT*.

For use in cements, a polymer is required which is rapidly crystallizable, and *Neoprene AC* and *CG* fulfil this need. These are polychloroprenes in the strict sense of the word, in that they are produced
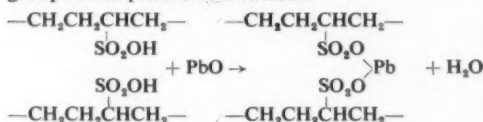

Figure 3. The conveyor belt with a cover of Hypalon synthetic rubber lifts hot salt from drier to storage bins. With the salt at 150° to 260°C, a belt coated with Hypalon lasted two to three times longer than other materials used previously (by courtesy of Du Pont)

from the one monomer. Another polychloroprene is *Neoprene S* which is a tough, cross-linked polymer used in the uncured state for oil resistant 'crepe' soles and similar purposes where good abrasion resistance is required and also for stiffening compounds containing the general purpose Neoprenes.

Although strictly not a development from the original Neoprene, *Hypalon* may be included here, for this polymer shows many similarities with the former. Chemically it is chlorosulphonated polyethylene and is formed by the reaction of polyethylene with chlorine and sulphur dioxide. In this way, chlorine atoms are introduced along the molecule and also sulphonyl chloride groups, there being one chlorine atom for every six or seven carbon atoms and one sulphonyl chloride group for every 90 to 100 carbon atoms.

Hypalon can be vulcanized by oxides of divalent metals; a minute amount of water, introduced in the form of wood rosin, is necessary to start the

reaction for it hydrolyses the sulphonyl chloride groups to sulphonic acid radicals

$$\begin{array}{ccc} -CH_2CH_2CHCH_2- & & -CH_2CH_2CHCH_2- \\ \quad\quad | & & \quad\quad | \\ \quad SO_2OH & & \quad SO_2O \\ \quad\quad\quad + PbO \rightarrow & & \quad\quad\quad\quad >Pb \quad + H_2O \\ \quad SO_2OH & & \quad SO_2O \\ \quad\quad | & & \quad\quad | \\ -CH_2CH_2CHCH_2- & & -CH_2CH_2CHCH_2- \end{array}$$

Like Neoprene, this polymer is resistant to oil, ozone, and heat: in the latter respect it is exceptional and helps to fill the gap which exists between the silicone rubbers and the nitrile rubbers (see for example *Figure 3*). Its price, 6s per pound, makes it suitable for use in applications where the high price of silicone rubbers would be unacceptable.

Nitrile Rubbers

These butadiene–acrylonitrile copolymers owe their oil resistance to the presence of the highly polar cyanide groups in the molecule. The intermolecular attractions caused thereby interfere with the entry of oil and solvent molecules into the spaces between the molecules of the polymer. In general, the greater the acrylonitrile content of the rubber, the greater the solvent resistance, but there is also an accompanying increased tendency to stiffen at low temperature. The temperature at which a definite degree of stiffening occurs may be reduced by the use of plasticisers, but these in themselves can cause trouble in contact with liquids, due to the possibility of their being leached out of the polymer. On the other hand it is sometimes possible to balance a small amount of swelling by the reduction in volume caused by loss of plasticizer, thereby giving a net zero increase in volume.

The heat resistance of this type of rubber does not seem to depend on the inherent chemical resistance of the polymer to oxidation so much as on the abnormally enhanced effect of antioxidants. The ozone resistance is much lower than that of the neoprenes and special additives called anti-ozonants have to be included in the compounds if exposure to atmospheres containing traces of ozone is at all likely. In recent years, polymers have been prepared with increased acrylonitrile content, and are finding use in the aircraft field where more exacting conditions of oil resistance are required.

Another recent commercial development in nitrile rubbers has been the introduction of copolymers of butadiene ($CH_2=CH–CH=CH_2$) with 2-methyl-5-vinyl pyridine

$$\begin{array}{c} CH_3 \\ | \\ \text{(N-pyridine ring)} \\ | \\ CH=CH_2 \end{array}$$
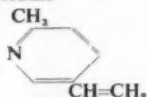
In addition to the usual vulcanizing reactions of the butadiene portions of the molecule, the vinylpyridine units will also react with benzotrichloride or benzal chloride, giving additional cross-linking or highly polar ionic groups which cause association. The final result on the physical properties is the same: an increase in the modulus of the rubber and in the oil resistance, coupled with improved low temperature properties.

A development of a similar nature is the formation of copolymers of butadiene, acrylonitrile, and a third monomer containing a carboxyl group. Besides the normal vulcanization with sulphur and accelerators, additional cross-linking can occur through the reaction of the carboxyl group with oxides of divalent metals such as those of zinc and magnesium. The final result is a polymer showing improvements similar to those of the vinyl pyridine rubbers.

Low temperature polymerization has also been used in making nitrile rubbers giving polymers with a high molecular weight and more regular structure. This causes slightly greater solvent resistance, but the tendency to stiffen at low temperatures is also increased.
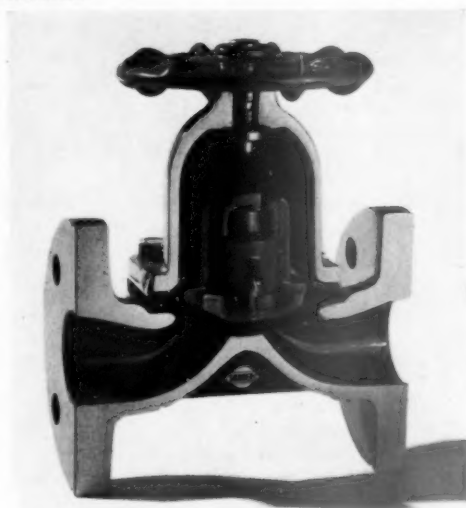

Figure 4. A Saunders valve with diaphragm of Hycar synthetic rubber (by courtesy of British Geon Limited)

Thioplasts

The first patents for thioplasts date back to 1926 and 1930 when J. BAER and J. C. PATRICK separately discovered that the reaction product of ethylene dichloride and sodium tetrasulphide was a rubbery material capable of being vulcanized by zinc oxide.

$$ClCH_2CH_2Cl + Na_2S_4 \rightarrow -CH_2CH_2-S-S-S-S-CH_2CH_2-$$
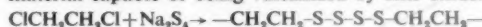
During the war many of these thioplasts were available, formed from various organic dihalides, differing proportions of the polysulphide sulphur being removed by after treatment. They were

Figure 5. Part of the equipment used for the production of polyurethane. Solid polyurethane is marketed by the Dunlop Rubber Co. Ltd under the trade name of ' Duthane' (by courtesy of Dunlop)

exceedingly oil-resistant, but possessed the disadvantage of a pronounced and disagreeable odour, especially marked when the vulcanizates were removed from the mould and during any subsequent heating. Today the number of solid thioplasts has been limited to a few special types, *Thiokol ST* may be cited as an example. It has good low temperature properties and also fairly good resistance to compression set. In addition there are liquid polymers for use in conjunction, with a low temperature curing system to give sealing and potting compounds, or they may be combined with epoxy resins for coatings and adhesives.

Butyl Rubber

The relatively slow response of butyl rubber to vulcanizing ingredients has always been a serious drawback to its use in the rubber industry. Both this and the oil-resistance of the polymer may be improved by halogenation. Brominated butyl, with
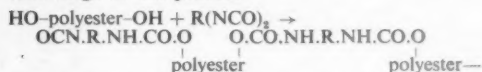
about two per cent of bromine, is commercially available as *Hycar 2202*. It has a rate of cure comparable with that of natural rubber and an increased resistance to oil and ozone. An application of a Hycar rubber is shown in *Figure 4*.

More recently there have been reports from America of a chlorinated butyl *ENJ-B11*, which is said to have very good resistance to heat and to flex-cracking. The degree of chlorination has not been revealed, and it has not been possible so far to obtain samples for evaluation.
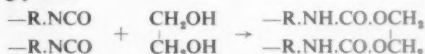
Both these halogenated butyls may be compounded with natural rubber, giving to the latter some of their ozone and oil-resistance. Developments in this field of mixed polymers have not been widely published and it seems likely that a greater use may be found for such compounds in future.
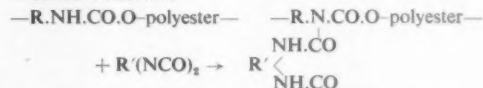
Polyurethanes

During the war German chemists were actively engaged in the synthesis of a synthetic rubber using polyesters as a basis. In this way they hoped to be able to use by-products of their chemical industry and thereby be independent of imports from abroad. The polyester, which may have a molecular weight of 2000 to 5000 is reacted with a di*iso*cyanate in a dough mixer. This produces an increase in chain length, molecular weight 4000 to 15,000, and also provides reactive centres which are utilized in the next stage of the process

$$\text{HO–polyester–OH} + \text{R(NCO)}_2 \rightarrow$$
$$\underset{\text{polyester}}{\text{OCN.R.NH.CO.O}} \quad \underset{\text{polyester—}}{\text{O.CO.NH.R.NH.CO.O}}$$

The chains are then further extended by the action of glycols

$$\begin{array}{ccc} \text{—R.NCO} & \text{CH}_2\text{OH} & \text{—R.NH.CO.OCH}_2 \\ & + \quad \rightarrow \\ \text{—R.NCO} & \text{CH}_2\text{OH} & \text{—R.NH.CO.OCH}_2 \end{array}$$

Finally, more di*iso*cyanate is added and the mixture cast into moulds. Reaction occurs between the urethane and the additional *iso*cyanate links to give a cross-linked structure. The rubber-like product is called *Vulkollan*

$$\begin{array}{cc} \text{—R.NH.CO.O–polyester—} & \text{—R.N.CO.O–polyester—} \\ & \text{NH.CO} \\ + \text{R}'(\text{NCO})_2 \rightarrow & \text{R}' \\ & \text{NH.CO} \\ \text{—R.NH.CO.O–polyester—} & \text{—R.N.CO.O–polyester—} \end{array}$$

If water is added at the second stage, liberation of carbon dioxide occurs

$$\begin{array}{cc} \text{—RNCO} & \text{—RNH} \\ + \text{H}_2\text{O} \rightarrow & \text{CO} \quad + \text{CO}_2 \\ \text{—RNCO} & \text{—RNH} \end{array}$$

and the final product is a foam known as *Moltopren*. Rubbers similar to both these are available in this country under various proprietary names (*Figure 5*).

Vulkollan is a highly abrasion resistant rubber of high tensile strength and fairly good oil-resistance; its resistance to dry heat is moderate but it is attacked by steam. The chief drawback is that these rubbers cannot be processed by the normal methods of the industry, and attempts have been made since they appeared to produce polymers which can be milled and press-cured like normal rubbers.

Adiprene B, produced in America, is a poly*ether*-urethane which may be milled for the addition of reinforcing filler, if desired, and the *iso*cyanate vulcanizing agent. *Adiprene C* is also said to be a polyurethane but is cross-linked by peroxides or by sulphur and accelerators. *Genthane S*, another poly-urethane, may be vulcanized by peroxides. The modifications necessary to make these polymers processable by the normal means of the industry have, however, caused a certain loss of tensile strength and abrasion resistance, and also of oil resistance. A further development along the same lines is represented by *Estane T* which is described as a ' virtually cross-linked polyurethane '. Although really a plastic, it displays rubber-like behaviour at room temperature and below. It has a high tensile strength as well as good resistance to tear, abrasion, solvents, oils, and ozone.

Silicone Rubbers

In 1945 both the Dow-Corning Corporation and the General Electric Company announced the development of silicone rubber. The simplest polymer of this type is represented by dimethyl-silicone rubber

$$\begin{array}{ccc} CH_3 & CH_3 & CH_3 \\ | & | & | \\ -O-Si-O-Si-O-Si-O- \\ | & | & | \\ CH_3 & CH_3 & CH_3 \end{array}$$
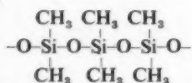
and although its tensile strength is not high, its working range of temperature ($-65°$ to $200°C$) is very large in comparison with organic rubbers. If a proportion of the methyl groups is substituted by phenyl, the low temperature limit can be extended to $-95°C$, although there is a corresponding small loss at the high temperature end of the working range. Fine particle silicas, specially treated for the purpose, reinforce the silicone rubbers to give much higher tensile strengths (approaching 2000 p.s.i.) but with some loss in the high temperature resistance. All silicone rubbers show excellent weathering characteristics but are sensitive to moist heat. They may be vulcanized by means of benzoyl peroxide, di*tert*butyl peroxide, or di-cumyl peroxide. *Figures* 6 and 7 show the production of silicone rubber at I.C.I. Ltd.

Among recent developments in the silicone rubber field may be mentioned the introduction of com-pounds which cure at room temperature, compounds which will bond to metals, and silicone polymers which do not show such a high permanent set when compressed: the latter improvement is obtained by the introduction of vinyl or allyl side chains which make the polymer more readily cross-linked. The chief impediment to the large scale use of silicone rubbers is their price: 35s to 40s per pound. They are therefore not used whenever a cheaper elastomers will fulfil or nearly fulfil the same function.

Acrylate Rubbers

The acrylate rubbers are polymers which may be used at moderate temperatures and go some way to fill the gap between the silicone rubbers on the one hand and the nitrile rubbers and neoprenes on the other. One of the most widely used is *Hycar 4021*, a copolymer of 95 parts of ethyl acrylate with 5 parts of 2-chloroethyl vinyl ether. Cross-linking is effected by polyamines, which react with the chlorine atoms.

$$\begin{array}{cc} CH_2=CH & CH_2=CH \\ | & | \\ CO & O \\ | & | \\ O.C_2H_5 & CH_2CH_2Cl \end{array}$$
ethyl acrylate   2-chloroethyl vinyl ether
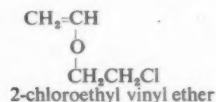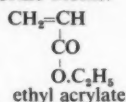
The tensile strengths exhibited by such rubbers are not high (about 2000 p.s.i.) and the low temperature properties are poor, but may be enhanced by the use of plasticizers: the latter however can cause the vulcanizates to be more sensitive to heat. Resistance to oil and ozone are excellent, but resistance to moist heat is poor. At 12s per pound these rubbers serve a valuable purpose and are widely used in all manner of O-rings, gaskets, printing rolls, and protective coatings for heat resistant fabrics.

Fluorinated Rubbers

Rubbers containing fluorine are the latest innovation in the synthetic rubber field. All show extreme resistance to oils and solvents and to many chemical reagents. *Poly FBA*, poly-1:1-dihydroperfluorbutylacrylate, is very resistant to nitric acid and to diester lubricants, although it has a low tensile strength; it may be cured by peroxides or amines. *Kel-F Elastomer*, which is a copolymer of monochlortrifluorethylene ($ClCF=CF_2$) and vinylidene fluoride ($CH_2=CF_2$) shows high tensile strength and good oil resistance, but its low temperature behaviour is poor; it is also not resistant to diester lubricants. The current price of these two rubbers is about £13 per pound.

Another product in the same price range is *Silastic LS 53*, sold as a ready compounded stock, which retails at £12 10s. per pound: this polymer is a fluorinated silicone rubber, and it is the sole example of an oil-resistant rubber which at the same time is

Figure 6. A section of the I.C.I. Nobel Division plant in Scotland where a finished sheet of silicone rubber stock is being removed from a mill (by courtesy of I.C.I. Ltd)
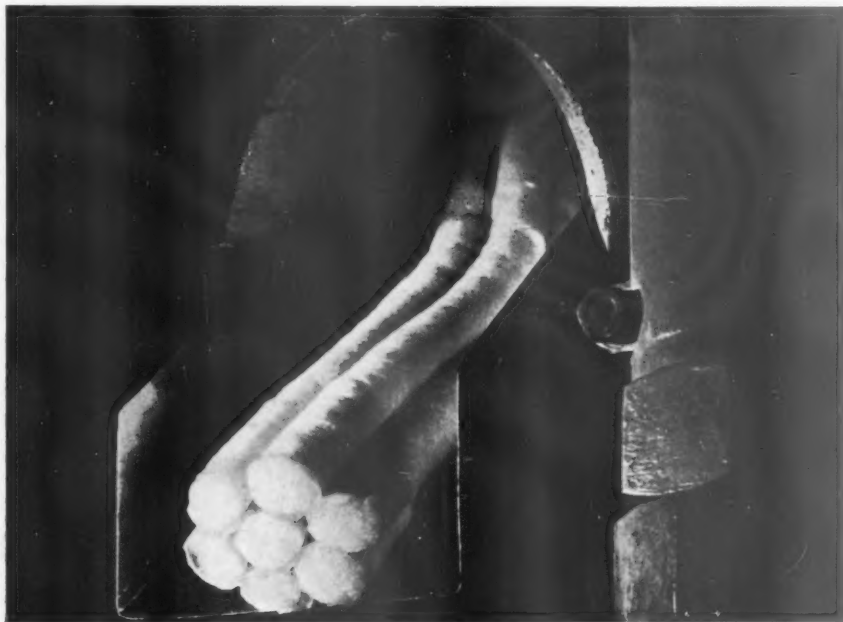

Figure 7. Extrusion of silicone rubbers at the I.C.I. Nobel Division plant in Scotland (by courtesy of I.C.I. Ltd)

Figure 8. An application of a fluorinated silicone rubber—a Silastomer asbestos shroud helps to carry the fiery exhaust gases from the Proteus turbo-prop engine to the jet exhaust pipe in the Bristol 'Britannia' (by courtesy of Midland Silicones Ltd and the Bristol Aeroplane Co. Ltd)

resistant to extreme heat under moist conditions (*Figure 8*). Needless to say its high price makes it once again very much a speciality rubber.

The last member of this series of fluorinated rubbers is *Viton A*, a copolymer of vinylidene fluoride and hexafluorpropylene ($CF_2=CF.CF_3$) which, at £6 per pound, is beginning to approach a price acceptable for general applications: carbon black or silica may be used as reinforcing fillers and the curing agent is hexamethylenediamine carbamate.

Conclusions

There are many industries which now require 'speciality' rubbers able to withstand certain specified conditions. The aircraft industry, for example, requires rubbers resistant to lubricating oils, fuel oils, hydraulic oils, and capable of maintaining their rubber-like nature at both ends of the temperature scale. The atomic energy industry requires rubber resistant to radiation as well as to heat. The industries servicing rocket projects require rubbers resistant to severe oxidation agents such as red fuming nitric acid, rubbers which will withstand high temperatures for the short space of time during which the rocket exists, even rubbers which may be used as fuel. The elastomers which have been described above go some way to meeting these requirements: usually they fall short in one or more respects or they represent a compromise between two mutually incompatible sets of properties.

During the years since the end of the War the number of different chemical varieties of rubber in commercial production has expanded, as well as the number of rubbers available within each class. The next twelve years should see an even greater expansion, as well as a considerable reduction in price of some of the more expensive kinds. Perhaps they will see the introduction of the ideal all-purpose elastomer which was recently humorously specified in the RABRM Bulletin in the following terms:

' The material must be a mono-elastomer available in massive and in latex forms, having the transparency of the acrylics, the low power factor of polyethylene, and the easy processability of natural rubber. It must be storable indefinitely in the open without massing; completely resistant to fungi, moulds, rodents, and marine borers; and soluble in the usual rubber solvents. Suitably compounded and cured it must resist all aviation and rocket fuels, hydraulic fluids, extreme pressure lubricants, corrosives (including boiling nitric acid); an operating temperature range extending from that of liquid helium to that of molten copper is mandatory. Besides the usual good mechanical properties of well cured natural rubber vulcanizates, it must be unaffected by high energy radiation, x-rays, α, β, and γ particles, neutrons, positrons, electrons, and cosmic rays (including neutrinos, protons, mesons, tauons, thetons, and hyperions). Desirably it should give off a non-toxic odour resembling that of lavender or violets in conditions of incipient decomposition. The price is a matter of indifference, provided always that it does not exceed the price prevailing at the time for natural rubber '.

REACTIVE DYESTUFFS
A New Method of Approach to Dyeing

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The recent development of textile dyeing and printing with classes of reactive dyes which chemically modify the fibre and give high fastness to wet treatments, has introduced a new principal to the theory of dyeing mechanisms. The sixty years of research which have given rise to this development are reviewed and the chemistry and technological implications of the new dyes for protein and cellulosic fibres are discussed.

For thousands of years, dyeing has been practiced empirically but it is only about one hundred years ago that man started to synthesize his own dyestuffs instead of extracting nature's rather inferior products. The use of extracts from plants or insects, *etc*, was developed to a very high degree by the early dyers but processing was generally long and the range of shades limited. Fastness to washing and to light was rare. The preparation of the first synthetic dyestuff by W. H. Perkin in 1856 and the discovery two years later of the diazo reaction by Peter Griess have led to an almost universal rejection of the use of natural products and the development of a tremendous organic chemicals industry. The preparation of synthetic dyestuffs of known constitution has resulted in a science of colour chemistry and over the past fifty years an increasingly detailed and precise study of the dyeing process itself.

When a textile material is immersed in a solution of a dyestuff, the solution may be merely imbibed or the dyestuff may transfer from the aqueous to the fibre phase. This transfer is the dyeing process. The discovery of dyestuffs or useful colouring matters depended for the greater part of its history on the empirical observations of whether this occurred or could be induced by adding salt, acid or heating the dyebath. Dyeing as a science was born when the reasons for this behaviour and the mode of attachment of the dye molecules to the fibre began to be studied. From this study three basic mechanisms emerged.

(*i*) the absorption of soluble dyestuffs by the fibre via attachment to active sites in the fibre, the fastness being determined by the mobility of the dye molecules in the fibre which may be reduced by hydrogen bonding, strong electrovalent links or aggregation. Dyes of this type may be exemplified by the direct cotton dyes or the level dyeing acid wool dyes which are acids forming salts with the basic groups in the fibre. These do not in general give a very high degree of fastness to washing although with wool dyes aggregation can give a very high degree of fastness, *e.g.*, the Carbolan dyestuffs of I.C.I. which are level dyeing acid dyes containing weighting groups conferring a high degree of affinity in neutral dye baths.

(*ii*) The absorption by similar mechanisms to (*i*) of temporarily solubilized dyes which are rendered insoluble by aftertreatment by oxidation, chrome laking or hydrolysis. These may be exemplified by the vat dyes rendered soluble by the alkaline reduction of the quinone system they contain, the chrome dyes for wool or the Alcian Blue type of dyestuff referred to below.

(*iii*) The construction in the fibre of a dyestuff pigment by the separate application of soluble components which react with one another. Into this category fall the azoic dyestuffs which are built up by diazotization and coupling and the Phthalogen dyestuffs[3] (Bayer) which are phthalocyanine precursors.

The post war years have been marked by a remarkable number of important dyestuff discoveries. The introduction of the 1:2 chromium complexes of the o:o-dihydroxyazo dyes for wool dyeing by the Geigy company[1] in 1949 has had a very wide effect in the wool trade where very high quality and levelness have been an absolute requirement for many years. In the field of cellulosic fibres we have seen the introduction of Alcian Blue 8GX, which by achieving temporary solubilization of the copper phthalocyanine molecule enabled dyers for the first time to produce fast to washing turquoise blue shades[2]. Another approach to this problem has led to the development of the phthalocyanine precursors which are applied to the fibre as soluble intermediates and then converted to the copper phthalocyanine derivative by suitable aftertreatments[3]. None of these developments, however, involved a basically new approach to dyeing. This honour was reserved

for the reactive dyestuffs introduced for both wool and cellulosic fibres between 1953 and 1956.

The reactive dyes introduce a fourth principle, that of reaction with the substrate to form a covalent link the resistance of which to subsequent treatments determines the washing fastness of the dyeing. Usually a reactive dye contains a labile halogen atom which reacts with a group in the fibre structure with the elimination of hydrochloric acid, but other types are also possible. Clearly the value of this approach to the dyestuff chemist is that the selection of the chromophoric system no longer depends upon the necessity for it to contain particular groups capable of reduction, chelation with metals and the like and the possibility of the use of the widest range of known chromophoric systems within a single range of dyestuffs for a particular fibre therefore exists. Theoretically the use of reactive dyes makes possible the highest degree of fastness to severe washing, abrasion, *etc*, although it must be admitted that this is not as yet true of the ranges of reactive dyestuffs which have appeared. However, a very high degree of fastness has been achieved, rivalling the best of the conventional dyestuffs in many ways and this with extremely simple chromophoric systems of brilliant shade.

Dyestuffs for Wool

Although the wool fibre with its wealth of potentially reactive amino, carboxyl and hydroxyl groups would appear to be the most likely first target for research into reactive dyestuffs this was not in fact the case. The literature contains few references to the attempted use of reactive dyes despite the fact that in the field of biochemistry the use of reactive compounds as drugs originated with P. Ehrlich in the early part of the century. In a broad sense it might be said that certain classes of wool chrome dyes are chemically attached to the fibre through the chelation of the chromium to both the dye molecule and the wool. The incentive for seeking reactive dyes for wool was not great since a very wide range of shades with very high washing fastness could be achieved with the old chrome dyes and the Carbolan dyes (I.C.I.) of the middle thirties and their successors. However reactive dyes for wool did offer potential, if unappreciated, advantages.

The first genuinely reactive dyestuff to appear for wool was Supramine Orange R (IG Farben) which was introduced in the middle thirties and had the following constitution

OH

N = N
SO₃Na   NHCO.CH₂Cl
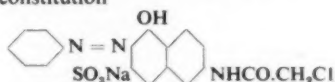
The chlorine atom on the ω-chloroacetylamino side chain is labile and capable of reaction under acid dyeing conditions between pH 1 and neutrality with amino groups in the wool fibre.

So far as can be determined there was absolutely no realization that this was the reason for its unusually high fastness to washing in view of its simple molecular structure. Supramine Orange R does not possess superlative fastness and this is probably the reason why it was not closely studied. Its low fastness arises from the fact that in common with all reactive dyes side reactions involving the aqueous solvent give rise to the hydrolysis product which has low fastness but retains its affinity for the fibre and causes staining of adjacent material in washing.

The reactivity of Supramine Orange R was, however, realized in the laboratories of Imperial Chemical Industries where work commenced on reactive dyestuffs in the early forties. The chloroacetylamino system does present certain disadvantages as a reactive system for wool dyes which has so far prevented the development of suitable dyestuffs.

Use of Unsaturated Reactive Side Chains

Research in Hoechst A. G. has taken another approach towards reactive dyestuffs for wool. Instead of seeking a reactive system containing a labile halogen atom, attention has been directed towards unsaturated systems[4] notably the vinyl sulphones ($-SO_2CH=CH_2$). This group will react with protein fibres (and also cellulose) by opening the double bond.

The most interesting feature of this system is the fact that the sulphate esters of the hydroxy ethyl sulphones will split out sulphuric acid under the right conditions to form the vinyl sulphone which will then react with the fibre. Thus it is possible to confer temporary solubilization on the dye making it easy to dissolve and apply and at the same time gain the advantages in fastness which accrue from having a sparingly soluble dye on the fibre.
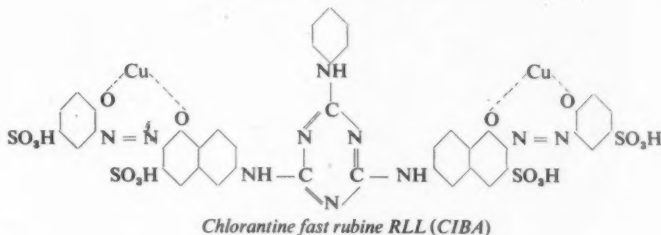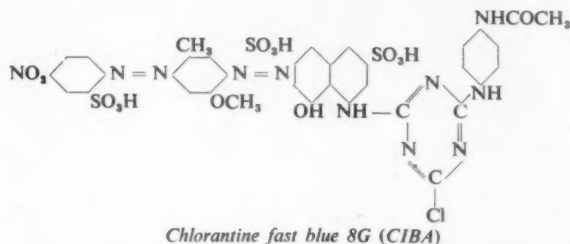
Three dyes of this type have so far appeared, suitable for wool, under the trade name *Remalan*. The shade range is at present limited to yellow and blue presumably due to inherent difficulties in preparing a red dyestuff fast to light containing this reactive system.

The Halogeno s-Triazinyl Group

The s-triazinyl radical is one which figures very prominently today in the reactive dyestuffs field. In the early twenties the Ciba company began to explore the use of the peculiar chemical properties of 2:4:6-trichloro-s-triazine. This compound as is well known gives stepwise reaction so that the first, second and then the third chlorine atoms can be

separately and quantitatively replaced. This type of reaction was used to prepare direct cotton dyestuffs by linking together two dyestuffs containing active amino groups, e.g.

Chlorantine fast blue 8G (CIBA)
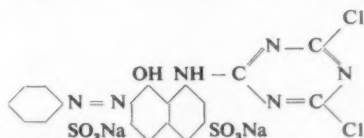

Chlorantine fast rubine RLL (CIBA)

In the course of preparative work many dichlorotriazinyl and monochlorotriazinyl dyes were prepared as intermediates and these in several cases were patented. One such case was the dye

which appeared in a patent filed in 1923 and described as giving fast pink shades on wool[6]. The reason for the fastness was reaction with the fibre but it was many years before halogenotriazinyl dyes were to appear for wool dyeing. In 1953–4 the Cibalan Brilliant dyestuffs were introduced to supplement the Cibalan range of Cibalan 2:1 chromium complexes. These are simple level dyeing acid dyestuffs for wool of no particular intrinsic fastness which contain the monochloro triazinylamino group and when the latter is reacted with the fibre become very fast.

However, the fastness achieved is somewhat less than can be achieved with conventional chrome dyestuffs or high molecular weight acid dyestuffs on wool and in this probably lies the reason for the lack of interest which marks the investigation of reactive dyes for wool. Such high fastness can be achieved without resort to reactive dyes over such a wide colour gamut that there is no obvious need for reactive dyes although some potential advantages may exist in this or that direction.
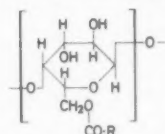
Dyeing of Cellulosic Fibres

This situation is however not true of cellulosic fibres. For long the shades available to the dyer faced with demands for wet fastness have been severely limited by the necessity to employ vat, sulphur or azoic dyestuffs with their characteristic molecular features, and the search for a practicable method for preparing reactive cellulose derivatives stable to washing treatments has been long and in many ways very thorough. Two approaches have been taken towards reaction with cellulose, to form either a cellulose ester or a cellulose ether. Both approaches have led to the development of reactive dyes for cellulose.

The formation of coloured cellulose derivatives via ester links has been the most widely studied.
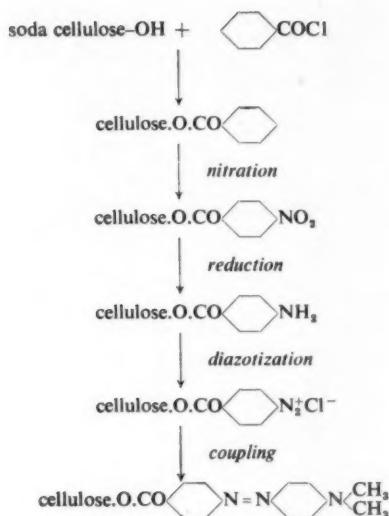

Esterification of Cellulose

C. F. Cross and E. J. Bevan were probably the first in this field[7]. They treated cellulose with strong caustic soda solution and then pursued the following sequence of reactions on the soda cellulose formed.

C

soda cellulose–OH + ⬡COCl

↓

cellulose.O.CO⬡

nitration

↓

cellulose.O.CO⬡NO$_2$

reduction

↓

cellulose.O.CO⬡NH$_2$

diazotization

↓

cellulose.O.CO⬡N$_2^+$Cl$^-$

coupling

↓

cellulose.O.CO⬡N = N⬡N$\langle$CH$_3$ CH$_3$

The dyed cellulose formed by this tedious and impracticable sequence of reactions showed high washing fastness. This approach was very thoroughly explored[8-11] by many workers. Only yellow to red shades could be obtained by this approach which was in any case hopelessly impracticable. In 1931 Ciba published a patent[12] in which the acylating agent was cyanuric chloride, after which work in this field would appear to have been virtually dropped until Imperial Chemical Industries entered the field in 1953 with the introduction of the Procion dyestuffs (see *Figures 1* and *2*) shortly afterwards[13].

The Procion Dyestuffs
The dominating feature of all the early work is the use of very strong solutions of caustic soda to produce soda cellulose, it being assumed that cellulose was a relatively inert substance. This would seem to be a relic of the work on the preparation of cellulose derivatives for use as fibres, *e.g.* cellulose acetate and triacetate, *etc*, where it is necessary to obtain a high degree of substitution of the glucoside chain to obtain a fibre of different textile properties. Treatment of cellulose with strong caustic soda causes very considerable shrinkage and is obviously of no value in a dyeing process. The discovery was made by I.C.I. that cellulose was very much more readily esterified than previously thought to be the case and that low degrees of substitution which are all that are required for a dyeing process can be readily achieved using alkalis as weak as sodium bicarbonate with a coloured acylating agent containing a dichlorotriazinyl group.

The result was the Procion dyestuffs which not only gave many of the anticipated advantages of reactive dyes, *e.g.*, brightness of shade, high wet fastness, *etc*, but also made possible a whole range of novel application methods leading to ease of application and greater productivity. In the course of this work the monochlorotriazines were also found to be reactive with cellulose under more severe conditions and new ranges appeared, the Procion ' H ' dyestuffs and the Cibacrons of Ciba who had reopened their studies on this topic. The monochlorotriazines are less versatile from the point of view of utility than the dichlorotriazines but offer the general advantage of greater stability in solution which is of value in many practical methods of application, notably textile printing.

Cellulose Ethers
Work on the formation of cellulose ethers started at a later date, but has been pursued more vigorously than that on esters.
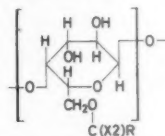
Etherification of cellulose, when X may be a hydrogen atom or an alkyl radical, etc.

D. H. PEACOCK[14] in 1926 obtained superficial colouring by boiling cotton in an aqueous solution of *m*-nitrobenzyl dimethyl phenyl ammonium chloride to form the *m*-nitrobenzyl ether of cellulose and this on reduction to the amine, diazotization and coupling with several naphthol sulphonic acids gave pink to brown dyeings fugitive to light. C. GRANACHER[15] obtained diazotizable fibres by superficial etherification of alkali cellulose freed from water with *p*-nitrobenzyl chloride and similar chloromethyl compounds or with dinitrohalogeno benzines followed by reduction. The initial reactions were carried out either in the melts of the halogeno compounds or in solvents at raised temperatures. Similar experiments were carried out by others[10,16-18] and the first direct use of dyestuffs themselves as etherifying agents was made by J. D. GUTHRIE[19] who found that by impregnating cotton with caustic soda solutions of the sulphate esters of alcohols and baking at 100 to 110°C for one hour or more, fast dyeings could be produced. Dyeings based on diazotized 2-*p*-aminophenoxyethyl sulphuric acid coupled with *p*-cresol, 2-naphthol-6-sulphonic acid were produced, as well as one based on the commercial product Solacet Fast Orange G (I.C.I.) which contains the required sulphate ester group.
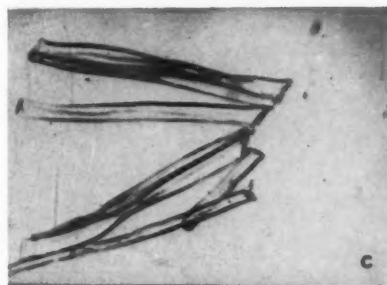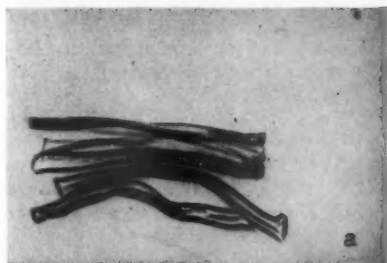
Figure 1. Cellulosic fibres are normally soluble in solutions of cuprammonium hydroxide due to complexing with the cuprammonium and destruction of the very strong hydrogen bonding which is the only force which renders cellulosic fibres insoluble in water. Cotton dyed with Procion dyestuffs, however, is rendered insoluble in cuprammonium hydroxide solution due to the reaction between the dye molecules and the fibre which interferes with the action of the solvent. Section (b) shows what happens when a drop of cuprammonium hydroxide solution is put on to the Procion dyed fibres shown in (a). The fibres swell but do not dissolve but the undyed fibres (c) are completely dissolved by the same movement (d)
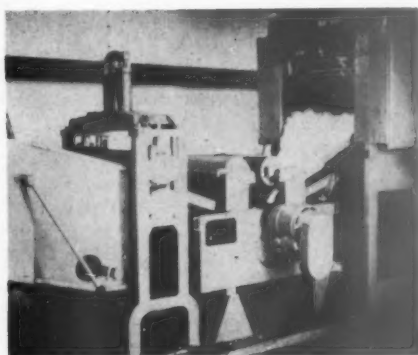

Figure 2. The introduction of reactive dyestuffs has enabled entirely new dyeing techniques to be employed for dyeing. Above is shown loose viscose rayon fibre being dyed continuously with Procion dyestuffs on a unit made by Fleissner & Sohn A. G. of Frankfurt, W. Germany. Normally, loose fibres are dyed by a lengthy batchwise procedure of low productivity. By using reactive dyestuffs, labour, time and capital can be saved while productivity is increased

The only practical use of this early work on cellulose ethers has been in the field of textile finishing. In the middle thirties Imperial Chemical Industries Ltd, introduced Velan PF, a new waterproof agent fast to dry cleaning, which as a quaternary ammonium compound reacted with the fibre when baked with an acid catalyst to form a cellulose ether after the manner of Peacock's experiments of ten years before.

The Remazol Dyestuffs

In the dyestuffs field success has only attended a new approach. Although in 1944 Ciba patented dyes prepared from diazo components containing, 3-sulphate ethyl sulphonyl groups and yellow end components[20], it does appear to have been realized that this system could be readily reacted with cellulose, by forming the vinyl sulphone (compare this with the Remalan dyestuffs for wool discussed above). Work at Hoechst A.G. however rapidly discovered the potentialities of this group[4] which led to the early introduction of two or three Remalan dyestuffs for wool and in 1957 the introduction of the Remazol dyestuffs for cotton. Whether the long period elapsing before the introduction of the cotton dyestuffs was due to difficulties in finding a practicable process for their application or the problem of finding fast to light bright red dyestuffs containing this group is not known.

Some Conclusions

Now that the use of reactive dyestuffs have been introduced and stood the test of bulk practice, a new importance has been given to a field of chemistry, that of natural and synthetic fibres. In many ways these show a degree of reactivity far greater than one would expect from a consideration of the potentially reactive groups they contain. This almost certainly arises from the fact that the fabrics also possess physical affinity for the dyestuffs which enhances the chances of reaction by virtue of concentration effects and possibly favourable steric factors on the fibre.

In the field of the dichlorotriazinyl dyestuffs for cellulose, the Procion dyestuffs (I.C.I.), there is already a considerable amount of published information[21,22] on the theory of the absorption and reaction of these dyestuffs and a renewed impetus has been given to the study of dyeing theory. The future will no doubt see as a result of the introduction of reactive dyestuffs for wool and for cellulose the discovery—and sometimes the re-discovery—of new systems giving better properties than those at present available and also the extension of the basic principle to the multitude of new fibres which represents the other side of the efforts of the organic chemist to advance textile knowledge and use.

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POWER TRANSISTORS

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This is the fourth article in the series on the technology of transistors. The three previous articles dealt with alloy junctions (September, page 335), silicon transistors (October, page 381) and germanium transistors for high frequency applications (November, page 425). Two more articles will be published in February and March; they will deal with the preparation, on an industrial scale, of ultra-pure germanium and silicon.

SINCE its invention[1] in 1948, the transistor has been well known to circuit engineers as a low power device. The first transistor was a point contact one with a power handling capacity of about 50 milliwatts. Today, ten years later, a typical value for a commercial audio output transistor is ten watts, while switching transistors handling about one kilowatt peak dissipation have been reported from various laboratories.

Two of the most important applications for power transistors are in switching circuits, where some power may be sacrificed to gain a good frequency performance, and in audio output stages, where the greatest possible power is needed. In the former class a five watt, ten megacycle silicon transistor has recently been announced[2]. However, in general, this type of transistor is still in the early stages of development, while audio output transistors between one and seventy watts are already commercially available. The design of high frequency low power transistors has already been discussed in a previous article[3].

In this article the main features of the electrical and mechanical design of power transistors will be discussed, with special reference to the problems of current gain and heat dissipation, and the present methods of solving these problems will be indicated. Since the electrical problems are similar in the high and low frequency devices, it is convenient to confine the discussion to the audio output type, and in particular the alloyed junction device, on which the most work has been done.

Electrical Characteristics

In most transistor applications, relatively low voltages are used, both for the convenience of the equipment design and for the low breakdown voltage of most present day transistors. Accord-ingly the power output of the transistor is most easily achieved by increasing the current handling capacity of the device. The main difficulty in this procedure is that at high current densities the transistor shows a considerable fall in current gain (*Figure 1*), which may easily lead to intolerable distortion in an amplifier.

The current gain can be interpreted physically as the product of three terms

$$\alpha = \alpha^* \beta \gamma \qquad \ldots . (1)$$

where γ is the injection efficiency of the emitter, β is the transport factor and α^* is the multiplication factor of the collector junction.

Injection Efficiency
A forward biased p–n junction emits minority carriers both ways—that is, injects holes into the n-type and electrons into the p-type material. In a transistor, the carriers injected into the base region are the only useful ones. The emitter efficiency is the ratio of this useful current to the total current across the junction, and is given by

$$\gamma = 1 / \left(1 + \frac{\sigma_b W}{\sigma_e L_e} \right) \qquad \ldots . (2)$$

where σ_e and σ_b are the conductivities of the emitter and base regions respectively, L_e is the lifetime in the emitter, and W is the transistor base width. For an alloy junction we may take $\gamma = 1$, which corresponds to a perfect emitter.

Transport Factor
The minority carriers injected at the emitter cross the base region to the collector by a combination of a random diffusion and a drift motion under the applied field. Some are lost by recombination with majority carriers and as a result the minority carrier current at the collector is slightly smaller than minority carrier current at the emitter. The ratio of collector to emitter current is known as the

transport factor of the transistor. If we neglect surface effects, the transport factor is given by the approximate expression

$$\beta = 1 - \tfrac{1}{2}\frac{W^2}{D\tau} \qquad \ldots\ldots(3)$$

where D and τ are the diffusion constant and life-time respectively for the minority carriers in the base region. For a well designed transistor, $W^2 \ll D\tau$, so that β is approximately equal to one.
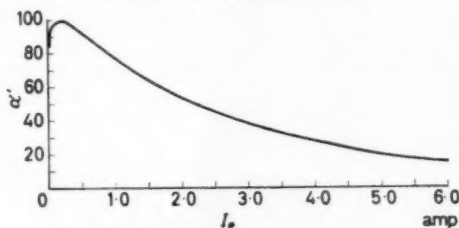

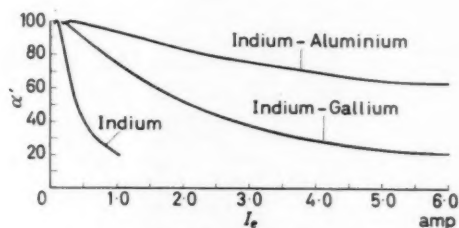Figure 1.   Variation of current gain with emitter current

Figure 2.   Relative fall-off in current gain for different emitter doping

Collector Multiplication Factor
This factor is strongly voltage dependent, but may be regarded as equal to unity for all normal values of voltage and current.

Effect of Increasing Current Density
The theory of the transistor first propounded by W. SHOCKLEY[4] and others[5] is valid only for very low current levels, where it can be assumed that the density of minority carriers injected at the emitter is very much smaller than the density of carriers already present in the base material. This assumption has two very important effects

(i) the minority carriers move from the emitter to the collector by a diffusion process.

(ii) the conductivity of the base region is not affected by the injected carriers.

As the current density increases, the density of injected carriers becomes comparable to the density of carriers already present. When this happens (i) and (ii) are no longer true. Minority carriers,

instead of merely diffusing at random over the base region, begin to drift towards the collector under the influence of the applied field. This process is known as 'field aided' diffusion, and results in a slight increase in the transport factor, β. At this stage the emitter efficiency is still constant, and hence we have, to begin with, the slight rise in α which may be seen in Figure 1. However, as the number of injected carriers increases, they begin to increase the conductivity of the base region, σ_b, This process is known as 'conductivity modulation'. and results in a decrease in emitter efficiency, as may be seen from Equation 2. This drop in emitter efficiency is the main reason for the fall-off in current gain at high current densities. One obvious method of decreasing this drop in emitter efficiency is to increase the area of the emitter junction. As an increase in the size of the collector and emitter junctions also is desirable from a heat dissipation point of view this is always done in power transistors.

In addition to increasing the area of the emitter junction it is also possible to increase the emitter efficiency by an increase in the conductivity of the emitter junction. In the case of an alloy junction transistor this is done by introducing into the emitter elements which have a high solid solubility in the recrystallized germanium. For a typical p–n–p alloy junction transistor where indium pellets are alloyed on to n-type germanium, the addition of very small amounts of gallium or aluminium to the indium pellet gives this high conductivity of the recrystallized region. The effect on a typical p–n–p power transistor can be seen in Figure 2.

Transistor Geometry
It has been pointed out that a large emitter area is desirable in order to achieve a high emitter efficiency at high currents. However, there are limitations to the increase in area that can be tolerated in an efficient conventional alloyed junction device. In
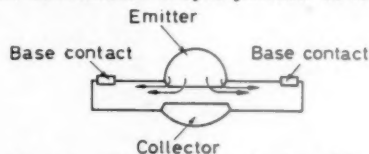

Figure 3.   Diagram to show the flow of the base current

an alloyed junction transistor the base contact usually takes the form of a ring surrounding the emitter pellet and the base current flows radially through the base of the semiconductor, as shown in Figure 3.

The resistance of the bulk material between the edge of the emitter and the base contact gives rise

to a voltage drop between the emitter and base. In addition, if the area of the emitter is large, then the resistance of the bulk material underneath the emitter pellet gives rise to an appreciable difference in voltage between the centre and the edge of the emitter. This transverse voltage drop, as pointed out by N. H. FLETCHER[6] means that in a conventional large area device, the centre of the emitter under normal biasing conditions is less positively biased than the edge and hence emits fewer minority carriers. This effect begins to be serious[7] when the emitter diameter reaches a value of $4Lp\sqrt{2}$ (about 3 mm in germanium) and above this value the effective area is given by

$$A_{\text{eff.}} = 2\pi r_e \cdot Lp\sqrt{2} \qquad \ldots (4)$$

i.e., the effective area concentrated in a annnulus round the edge of the emitter of width $Lp\sqrt{2}$ (about 0·7 mm in germanium). Hence for emitter junctions above ten sq mm in area, the circular geometry becomes uneconomic.

The problem set by the transverse voltage drop across the emitter has been overcome for very high current devices by the simple expedient of having several base or emitter contacts. Typical geometries are shown in *Figure 4*. By restricting the width of each of the emitter rings, or strips, below the critical distance the entire area can be used efficiently. In each geometry, a very large collector is alloyed or evaporated on to the other side of the wafer. By using a transistor of the ring type with several emitter ring types Fletcher[8] has achieved currents of 40 amps with switching powers of one kilowatt.
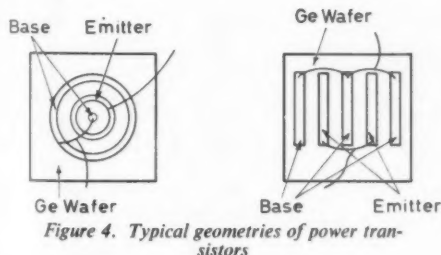

Figure 4. Typical geometries of power transistors

Heat Dissipation

In a power transistor considerable heat can be generated at the collector junction, and its removal is the principal object of the mechanical design of the device. This is of particular importance, since one of the main defects of the transistor as a circuit element is the very large variation in reverse current with temperature. The reverse saturation current of a *p–n* junction in germanium doubles for a rise

in temperature of twelve degrees centigrade, while the saturation current for silicon doubles itself every eight degrees. Thus comparatively modest increases in ambient or working temperatures can easily lead
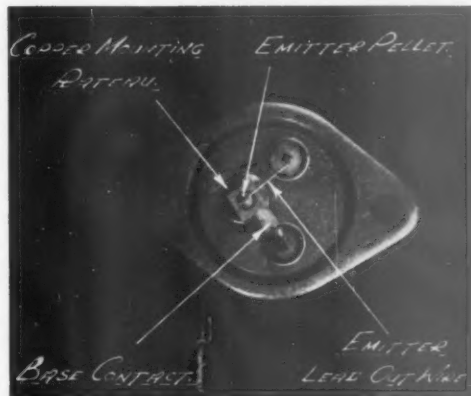

Figure 5. Typical power transistor mounted on base plate

to a runaway condition which can cause failure of the circuit or of the transistor itself.

The ability of the transistor to remove the heat generated in the crystal is usually measured in terms of a thermal resistance θ (°C/watt) which is defined by the relation

$$T_j = T_{\text{amb}} + \theta W \qquad \ldots (5)$$

The thermal resistance is always quoted as the sum of an internal and an external component. The internal thermal resistance (from collector junction to transistor case) depends on the design of the transistor envelope. Since the largest contribution to the internal thermal resistance arises from the collector pellet itself, this is kept as thin as possible and in most alloyed junction power transistors is soldered directly to the base plate of the envelope. This base plate is usually made of copper, for good thermal conductivity, and will in turn be bolted or tightly screwed to the chassis. In a well designed transistor θ_i will be about 1°C per watt.

The external thermal resistance, between transistor case and ambient atmosphere, depends mainly on the chassis on which the transistor is mounted, and on the quality of the ventilation around it. Since a typical value of θ_e may be 6°C per watt it is obvious that the external thermal resistance is usually the limiting factor in the allowable dissipation of the transistor. For high power diodes and transistors forced air cooling and water cooled systems have been used.
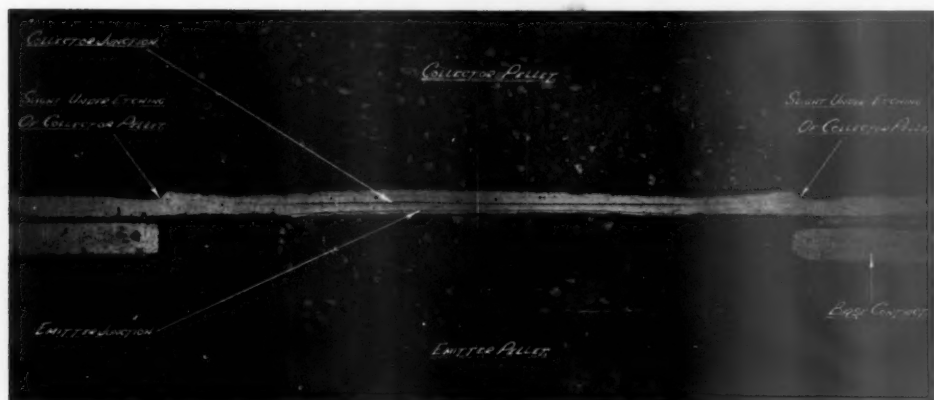
Figure 6. Cross-section of a commercial power transistor designed for switching applications. The size of the collector and emitter pellets are 0·1 in. and 0·06 in. respectively, and the inter-junction distance is about 0·001 in. This unit is capable of giving 7 watts at 500 kilocycles on a heat sink whose thermal resistance is 4°C per watt. The particles visible in the collector and emitter pellets are particles of grinding powder

Different Types of Junction

The different types of junctions will now be briefly considered from the point of view of power transistors.

Grown Junction

This type has already been dealt with by J. T. KENDALL[9]. The junction is formed by altering the impurity type in the melt while the crystal is being pulled from the melt. Although grown junction germanium transistors have been made with dissipations of a few watts, the method does not lend itself to high power transistors, mainly because it is difficult to avoid a thick collector layer of high thermal resistance, and also because the elaborate geometries shown in *Figure 4* cannot readily be obtained by the grown junction technique.

Diffused Junction

By placing an impurity on the semiconductor surface of opposite type to the base, and heating to elevated temperatures, solid state diffusion can take place. A $p–n$ junction will then be formed below the crystal surface at a depth governed by the temperature and time of diffusion[10]. Very flat junctions can be obtained by this method, and large area junctions are no more difficult to form than small area junctions. The junction area and shape can be defined by either masking during deposition of the impurity film or by masking and etching after diffusion. The impurity material can be deposited either from the vapour phase or by painting the surface.

The disadvantage of this technique as far as audio frequency power transistors are concerned is that the emitter efficiency obtained is lower than that obtained by alloying, and leads to an inferior α' *versus* current relation. The main reason for this is that the conductivity at the emitter junction is lower than for the alloyed junction type. On the other hand, the double diffused[11] and the alloy diffused[12] techniques now being used for high frequency transistors make this a very promising type in the high frequency medium power range[2], due to the very small base widths which it makes possible.

Alloyed Junctions

Alloying is the technique most generally adopted for commercial power transistors. It gives the best method for introducing into the emitter those elements which have a high solid solubility in the recrystallized germanium. This in turn leads to a high emitter conductivity and good injection efficiency, as previously discussed. The alloying technique also offers the opportunity of obtaining the emitter and base geometries shown in *Figure 5*.

The most commonly used method of making $p–n–p$ alloyed junctions consists of placing a pellet of indium on to a crystal of n-type germanium, and heating the assembly to about 500°C. When the assembly cools, the recrystallized germanium has dissolved enough indium to make it p-type. If other p-type impurities, such as gallium and aluminium[13] are added to the pellet before alloying, the concentration of p-type impurity in the recrystallized layer is increased, and the con-

ductivity of the *p*-type region is greatly enhanced. For *n–p–n* transistors the pellets used are generally either arsenic or antimony in the form of an alloy with some suitable metal such as lead. Considerable research is still being carried out on new methods of forming alloyed junctions—particularly for the large area narrow base width emitters already described—and on increasing the conductivity of the emitter.

A cross section through a commercial *p–n–p* power transistor designed for switching applications is shown in *Figure 6*. By a suitable choice of heating cycle, and close control of pellet weight and wafer thickness a constant inter junction distance can be achieved over most of the active area of the transistor. This is of importance in view of the increased effectiveness of the edge of the emitter at high current densities, as previously discussed.

Conclusions

Considerable advances in power transistors have been made since the earliest point contact types. Present day commercial transistors offer audio power outputs in the range from one to seventy watts. The new techniques and geometries being developed which have been described in this article offer the prospect of yet further increases in higher power and higher frequency transistor performance. Already switching powers in the kilowatt region, and

dissipations of several watts at tens of megacycles are being reported in the laboratory. When these devices are fully developed, advances in transistor performance comparable with those already achieved over the original point contact transistor will have been accomplished.

The authors wish to thank the Directors of Mullard, Ltd for permission to publish this paper and Dr E. A. Roberts for critical reading of the manuscript.

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Computers and Instruments

THE age of the computer has arrived with the first Electronic Computer Exhibition held in London, from November 28th to December 4th, 1958. The new developments were hardly startling but the fact that computers and their associated equipment can fill the National Hall at Olympia is significant. Over the past few years the speed of operation has increased, new types of memory stores have been developed and transistors have replaced, or will replace, valves.

In order to speed up a computer, the information must be fed into the instrument at the same speed or faster than the time it takes for the operations to be performed. To do this, the keyboard should be replaced by an automatic reader; ERA developed by the Solartron Group was the first of these and is now being used by Messrs Boots Ltd. Another and much less expensive reading machine is being developed by E.M.I. The latter is at present limited to use with a special type face—the photocell in fact scans the position and amount of black compared with the white in a series of small vertical elements—and it has been developed with a

view to using the machine for cheques. The printing ink can be of the magnetic type, and by replacing the photo-electric cell with a magnetic scanner, defaced cheques will not affect its operation. The output of computers must similarly be increased and for this purpose the Rank Precision Industries have developed a machine which prints up to 1500 lines per minute with about 130 characters per line; the information after being received from the computer, is recorded on a sensitive drum and printed using the xerographic principle.

ACE the fast computer developed by the National Physical Laboratory was also introduced at the end of November. It is, of course, an experimental machine but it can, for certain types of operation, work ten times faster than any existing commercial computers.

The Physical Society

The Annual Physical Society Exhibition will be held this year from the 19th to 22nd January, 1959, at the Royal Horticultural Hall. It will, as usual, ' put on show ' all the research tools the physicist may wish or need to use in his research and development work.

D

NUCLEAR PROPULSION

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This article is based on a lecture presented to the British Association, Glasgow, September 1958. It summarises, very briefly, the economics of nuclear power for ship propulsion and the types of reactor systems which could best be used for mobile reactors. It is pointed out that mobile reactors present difficult shielding problems as weight must usually be kept at a minimum.

THE rapid growth in the number of land based nuclear power stations in operation or under construction has naturally led to a fairly wide public belief that nuclear power plants for propulsion purposes will be equally rapidly produced. News of the satisfactory operation of the United States package power reactor, of the building of the first nuclear powered surface ship *Savannah* in the United States (*Figure 1*), of the construction by the Soviet Union (see *Figure 2*) of the nuclear powered ice-breaker *Lenin*, and the recent exploits of the submarine *Nautilus*, all perhaps tend to lead one to believe that there are no real barriers to quite early and wide adoption of the fission reactor in ship, air, rail or any other form of transport.

Unfortunately this is not the position. Whilst the feasibility of application is not in doubt· for most propulsion purposes, the extent to which it is developed and used depends, as always, on the answer to the question ' Is it worth it? '. The answer is influenced by the approach used. Militarily for instance, as in the case of the submarine where nuclear propulsion confers high speeds under water for long periods without the need of oxygen for combustion, it gives substantial operational advantages and a high degree of invulnerability which is obviously worth the extra cost. Another approach might be that which looks at the strategic aspect of lessening one's dependence on the overseas oil supplies. Widespread conversion to nuclear propulsion would undoubtedly lessen one's dependence on this fuel but, as will be seen later in the paper, not appreciably so. The third approach is the commercial one which is to determine whether any new method of propulsion would enable one to do the same job as cheaply as, or preferably cheaper than the use of conventional and proven machinery—or alternatively do a commercially attractive job that could not possibly be done by any other means.

A satisfactory answer to the first approach would permit limited usage. A satisfactory answer to the last would open the way to widespread use. We have not yet reached the latter stage, however, and this paper goes into some of the questions and examines the facts of nuclear power to determine how they affect the answers particularly in relation to the shipping application. Whilst it is feasible to apply it to aircraft propulsion—and the military application, which involves fewer shielding problems than the commercial side, is being worked on in the United States—the attractions are not so obvious as for shipping. Nuclear power could be applied to locomotives, but since it would be much simpler to apply it indirectly in the form of electrical power generated more safely and economically in nuclear power stations, nuclear locomotives are not likely to be seen in the United Kingdom.

Basic Features of Nuclear Power Plants

Nuclear power plants are characterized by the following main features:

(*i*) Great endurance, or low fuel consumption per unit of energy released, *e.g.*, the energy released by the fissioning of one gram of uranium 235 would give about one megawatt of heat for a day or the equivalent of 32,000 shaft horse power hours.

(*ii*) Independence of oxygen for combustion.

(*iii*) Potentially considerable power can be obtained from a small volume.

(*iv*) Radiation.

The first three represent the attractions of nuclear power which might be expected to give the vehicle operator all that he needs. The last feature, that of radiation, which always accompanies fission, is unfortunately the compensating disadvantage, and
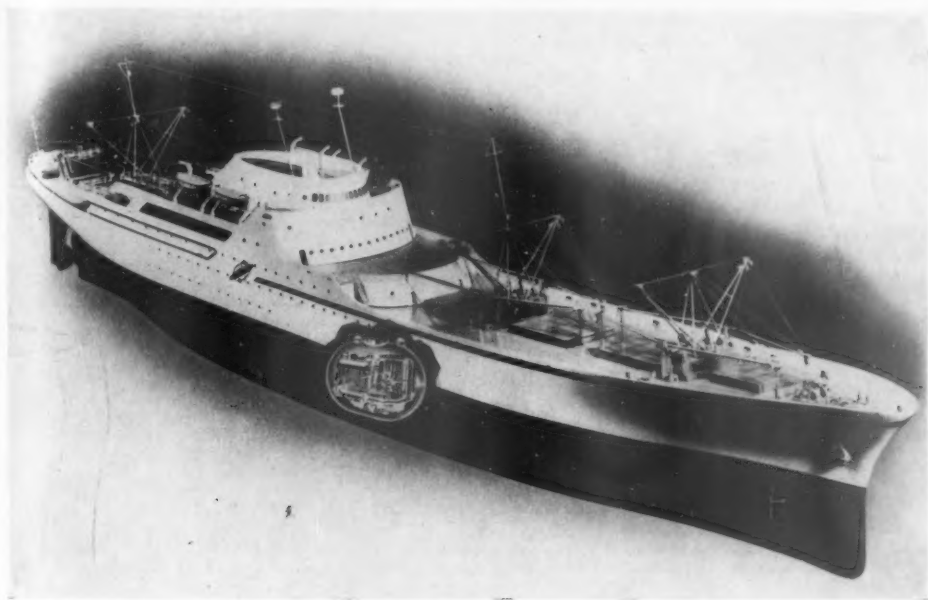
Figure 1. A drawing of the nuclear ship Savannah, *which will be the first commercial nuclear powered ship. The drawing shows the basic design features and the location of the nuclear reactor, which is designed to operate for over three years on its initial fuel loading.*

as will be seen, has such widespread effects in design, operation, maintenance, safety and costs of nuclear plants that it represents the biggest obstacle to the widespread mobile application of nuclear power.

Mobile propulsion plants demand small specific weights (lb/shp), small specific volumes (ft³/shp), small capital and running costs, low maintenance, and, since risks inevitably accompany mobility, high reliability. The consequences of failure of the power plant differ for various applications but usually they are dangerous or costly or both. An analysis of radiation and its repercussions will show how this factor affects the above considerations.

Radiation arises from the fission of uranium 235 nuclei which result in the release of high energy neutrons and gamma photons, and the formation of fission fragments. The latter are usually retained within the cladding of the fuel element but their radioactive decay results in the emission of further gamma and beta radiation. The coolant used to remove the heat of fission from the core is, generally, also intensely active releasing gamma photons as a result of the activation by neutron bombardment while passing through the core. Any corrosion

particles from the primary circuit which are picked up by the coolant and passed through the core also become activated and emit further gamma radiations. It should be remembered in considering the overall effects of fission and radiation, which are sub-divided into broad headings below, that the reactor is simply a source of heat, and when taken with its associated coolant, the heat exchangers, and the shielding merely replaces the boiler and fuel of the steam plant, or the combustion chambers and fuel of the gas turbine.

Shielding
Local protection must be provided in the form of shielding against the neutron and gamma radiations in order to safeguard the crew and passengers of the vehicle. An example of the radiation from a high powered operating reactor can be given by the fact that the neutron intensity at the surface of the unshielded reactor is about a billion times greater than the biologically permissible level; the gamma intensity is very nearly as great. One would in fact have to be about two miles away from an unshielded high power reactor to lower the dose rate to the maximum permissible level (1 mpl). Even a quarter of an hour after shut down, because

of the activity from the decaying fission products, one would still acquire a lethal dose at a 100 ft in just over half a minute.

Overall shield weights, which can range from under 100 tons to 1500 tons or more, are dependent upon the initial size of the reactor, upon the specified radiation levels outside the shield, the materials used for shielding, the arrangement of the primary coolant circuit and other components, and the type of coolant used. Substantial weight savings can be achieved in certain circumstances by permitting radiation to escape in localized directions where they can do no harm. In a submarine, for instance, use could be made of the fact that the reactor is below water level and radiation could be permitted to escape athwartships. The same principle would have to be used in aircraft reactors, and, provided precautions are taken against radiation scattered back into the vehicle as result of collisions with atoms of the surrounding media, is at times a feasible method of weight saving. The effect of providing the necessary shielding is of course greatly to increase the overall size of the plant and the capital cost associated with it.

Table 1. Comparison of reactor types

Reactor type	Advantages	Disadvantages
(1) Pressurized water reactor (PWR)	Compactness. Low weight. Small heat exchangers. Good stability, *i.e.*, large negative temperature coefficient. Rapid response to power demands. Low pumping power. Proven in the U.S.A. in submarine form, power station form and APPR. Being applied to U.S.A.'s first surface ship *Savannah*. Being developed in U.K. for submarine application. Some development possible by permitting local boiling.	Enriched fuel required. Poor steam conditions hence relatively low efficiency cycle. Corrosion problems. Relatively high pressure system, 1500 to 2000 lb per sq. in. Reflected in containment problems. Primary circuit active during operation. Mainly $\times O^{16}$ (n,p) N^{16} 7·4 sec half-life, 6 MeV gamma.
(2) Boiling-water reactor (BWR)	Closely related to PWR technology. Lower primary circuit pressures. No pressurizer. If direct cycle used, no heat exchanger required but main propulsion machinery may then require shielding. Possibility of natural circulation, avoiding pumps and valves in primary circuit. Prototypes operating in U.S.A.	Enriched fuel required. Corrosion problems. Primary circuit active. Main machinery active unless efficient separating system developed or indirect cycle used, when a heat exchanger is required and the advantages of compactness reduced. Control more complex than PWR due to steam voids in core and effect of power changes on these.
(3) Organic liquid moderated reactor (OLMR)	Low-pressure primary circuit. Corrosion negligible. Good lubricating properties of liquid. Low induced activity. Large negative temperature coefficient.	Liquids unstable under irradiation and temperature above 400°C. Polymerization products, make up and removal required. Suitable organics solid at NTP, requires trace heating. Fire risk. Hydrogen evolution. Poor heat transfer properties (about 1/5 as good as water for same pumping power). Enriched fuel required.
(4) Gas-cooled graphite-moderated	Natural uranium could be used although plant would then be unacceptably bulky. Reasonable steam conditions. No temperature limit imposed by coolant. Can increase specific output by higher gas pressures and gas temperatures, and by use of better structural materials such as Zr or Be canning, ceramic or cermet type fuels and enrichment. Proven system in power station form. Less energy in total primary circuit and containment may be easier than for PWR.	Large, heavy reactor. High pumping power. Large heat exchangers. Slow response. Poor heat transfer characteristics of gases. Wigner effects in graphite. Will require enriched fuel for mobile applications. Not yet developed in compact form suitable for propulsion.
(5) Gas-cooled heavy-water moderated	Natural uranium could be used. Much as for (4).	Large and heavy reactor although less than (4). Expense and limited availability of moderator. As for (4) except for Wigner effects. Complex design to separate moderator and coolant. Will require enriched fuel to make small enough for mobile purposes.
(6) High temperature gas cooled reactor (HTGC)	Use of gas as coolant at 750°C outlet temperature permits the use of a relatively efficient gas turbine plant and therefore compact main propulsion machinery.	High temperature coolant implies high fuel element temperatures of order of 1000°C at surface. Dispersed type fuel elements required for heat transfer purposes. Enriched fuel required. Not yet developed.

Figure 2. The Soviet ice-breaker vessel, Lenin, *under construction. The stage shown here was reached in the early autumn of 1958. The ship will exert a pressure of 330 tons when travelling at 2 knots in a solid ice field up to about 8 ft thick. The maximum speed in the open sea is 18 knots (reproduced by kind permission of the Editor of* Discovery)

Shut Down Heat

A further peculiarity of a fission reactor is that when the reactor is shut down there will still be intense radiation resulting from the decaying fission products in the fuel, although this activity, which is accompanied by heat generation, decreases with time as the short lived products die. For example, if one considers a 60 megawatt heat reactor, then after a prolonged period at full power the activity of the fission products might amount to 3×10^8 curies, equivalent to several hundred tons of radium. The heat generated after shut down would range from seven to eight megawatts two seconds after shut down to just about one third of a megawatt some five hours later. Provision must therefore be made for cooling the reactor core for some considerable time after shut down and this coolant must be available under all conceivable accident conditions. If it is not provided there would be a serious danger of melting the core and releasing the fission products contained within the fuel elements.

Accident Precautions

This feature of guarding against the accidental release of radioactivity is a major requirement. The repercussions of the accidental release of even part of the fission product activity if it occurred anywhere near a population centre would obviously be serious indeed. One has only to consider the effects of the release from Windscale to realize how much more difficult the protection problem becomes once radioactive particles become loose. Not only could there be the direct radiation from the fission cloud, the effect of which would decrease rapidly due to dispersion and decay, but the more serious possibility of ingestion through ground contamination. The remote siting of land based power reactors is an example of the care taken at this stage of development even with relatively proven systems.

Precautions will therefore have to be taken with the mobile reactor to contain the fission products mentioned in the earlier paragraph in the event of accident conditions leading to their release from the core and the primary coolant circuit. This is obviously difficult for systems where there are increased risks associated with movement, and perhaps the aircraft case represents an extreme example of the problems of guaranteeing containment under all conditions. The problem differs in detail with different reactor systems; some, because of a large negative temperature coefficient are inherently stable. Examples of this class are to be found in the liquid moderated reactors such as the pressurized water system. Other systems, such as the organic liquid moderated reactor, might have an inherent fire risk associated with the particular coolant used. The effect of providing the means to contain the fission products in the event of any forseeable accident condition again inevitably adds to the overall size and cost.

Material Damage

Further effects of radiation are found in the changes in the properties induced in most materials by neutron and/or gamma doses. Plastics and rubbers harden and embrittle, resistances, conductances, capacitances change their basic values, and lubricants break down. The properties of the important structural materials such as steel and graphite are affected, being demonstrated in the latter by the Wigner growth and stored energy, and in the former, in those steels exhibiting a brittle–ductile transformation by a raising of the transition temperature. The latter may be raised as much as 50 to 100°C in certain steels by a total irradiation of fast neutrons of the order of 10^{19}.

These aspects have to be guarded against and usually result in the use of rather special materials which again generally add to the overall cost when compared to conventional machinery.

Manoeuvrability

Some of the fission products decay to produce isotopes which capture neutrons readily. These are known as poisons and cause a loss of reactivity in the system which has to be catered for in the design of the core by building in more fissile material. Xenon 135 is a particularly troublesome poison in that although the xenon concentration reaches equilibrium when the reactor is at power, on shut down the poison continues to build up for several hours, as a result of its formation as a decay product, until it reaches a maximum, after which it slowly decreases. If allowance is not made for this then the state can easily be reached when after shut down for a few hours, it would be impossible to start up the reactor for some considerable time. The rate of power can also change be limited by this effect.

Maintenance

Any component of the primary circuit, such as the pressure vessel, which is subjected to neutron bombardment will become radioactive, and inspection will become exceedingly difficult. Furthermore any components in the primary circuit through which the coolant flows are likely to pick up activated corrosion products which may adhere to the components and these will then become radioactive and inspection and maintenance will be complicated by the fact that decontamination will have to take place before anything but remote handling can be employed.

Health Support

A final aspect arising from radiation is the need to supply the necessary health physics support in monitoring radiation levels, in keeping a check on the radiation doses which personnel receive and to provide any decontamination centres which may be required.

The foregoing outlines the main factors which have to be considered when debating whether or not to provide nuclear power for propulsion purposes. *Table 1* gives the pros and cons of the various systems which are likely to be considered in the near future for mobile purposes.

In studying *Table 1* it must be remembered that only two systems have in fact been proven at this moment. These are the gas cooled graphite moderated reactor which has been proven in the Calder Hall plants, but which has not been developed for mobile purposes, and the other is the pressurized water reactor system which has been proven in its mobile but highly expensive form in the submarine *Nautilus* and which has also been

Table 2. Approximate Relative Values of Size, Heat Loadings in Different Reactor Systems

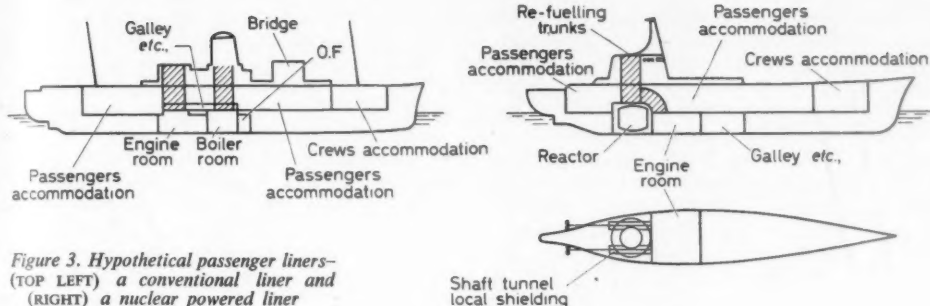| Reactor type FUEL	Natural uranium	Natural uranium	Slightly enriched uranium	Highly enriched uranium	Slightly enriched uranium	Highly enriched uranium	Highly enriched uranium	Natural uranium	Slightly enriched uranium	Highly enriched uranium	Slightly enriched uranium
MODERATOR	Graphite	D_2O	Graphite	Graphite	Water	Water	Organic liquid	D_2O	Graphite	Fast reactor	Boiling water reactor
COOLANT	Gas cooled	D_2O	Gas	Gas high temperatures	Water	Water	Organic liquid	Gas cooled	Sodium cooled	Sodium cooled	Water
Approximate relative core dimensions (diameter of right cylinder in feet)	25 to 30	10 to 12	13 to 14	6	5 to $5\frac{1}{2}$	2	$6\frac{1}{2}$	13 to 14	8	1	5 to $5\frac{1}{2}$
MW (heat) per cu ft	$\frac{1}{100}$ to $\frac{1}{50}$	2	$\frac{1}{50}$ to $\frac{1}{10}$	2	1 to $1\frac{1}{2}$	4 to 5	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{5}$	30 to 50	1 to $1\frac{1}{2}$

Figure 3. Hypothetical passenger liners—
(TOP LEFT) *a conventional liner and*
(RIGHT) *a nuclear powered liner*

built in power station form at Shippingport in the United States. *Table 2* gives the approximate relative values of size and heat loadings in different types of reactor systems. It emphasises the necessity to enrich the fuel elements in the highly expensive uranium 235 isotope if one wishes to reduce the core size substantially. Small size is desirable in itself in any mobile plant in order to increase pay load capacity but is particularly so in nuclear plants since from a small core stems a smaller pressure vessel, a smaller volume and weight of shielding, a smaller containment vessel, and therefore a smaller overall capital cost. However, if one uses the uranium 235 isotope to achieve it, then the fuel costs will be increased.

Application to Ships

The feasibility and practicability of propelling ships by nuclear power is not in doubt. The performance of *Nautilus* which steamed 69,000 miles on its first core charge, equivalent to some 2,000,000 gallons of diesel oil, has amply demonstrated this. The fact that it costs nearly 20 times as much to do this as with ordinary fuel is not significant in terms of the operational advantages conferred on the submarine. Although it is an extreme case in which capital and development costs were high, and highly enriched and expensive fuel elements were used, the expense involved underlines one of the main problems preventing ready acceptance of nuclear propelled ships in general.

A quick survey of the other countries' activities indicates intense theoretical interest in most countries, but apart from the United States which is building the *Savannah*, and the Soviet Union which is building the ice-breaker *Lenin* (see *Figures 1* and *2*) not much practical work for non-military purposes is being undertaken. It is not difficult to see why this hesitancy is so widespread. The principle effect of using nuclear power is to give very long endurance

with negligible fuel consumption and a ship may be able to go for some three years without refuelling. However, long endurance or small fuel consumption in itself is not the dominating issue in the commercial field, which uses as its datum the cost per ton of cargo carried. The latter must be seen to be capable of being brought below similar costs using conventional machinery to justify the large scale capital and technical investment involved in the wide application of nuclear plants. The overall running costs derive from expenditure under three broad headings as follows:

(i) *Capital Cost*—This includes the capital cost of the whole machinery and equipment and is reflected in the overall running costs as a result of the subsequent repayments and interest on the capital borrowed.

(ii) *Fuel Costs*—This includes the fuel investment cost, the fabrication charges, the burnup of the fuel and the reprocessing charges. The actual amount of fuel burnt up, *i.e.*, the direct fuel costs, are of course low with nuclear systems.

(iii) *The Basic Costs*—These are the costs due to insurance, wages, stores, dues, port charges, *etc.*

Many investigations have been carried out both in the United Kingdom and the United States on the relative economics of nuclear and conventional ships and the conclusion to be drawn from all of these is that the total operational costs of the former range from 10 to 40 per cent greater than the latter. These are complex studies having to take into account the capital costs, machinery weights, load carrying capacity, trip distances, oil fuel prices, uranium prices, credits allowed for plutonium generation, service speeds, load factors, interest rates and so on, and since much uncertainty exists in many of these items, particularly future prices of oil fuel, uranium 235 and plutonium 239 it is not surprising that this degree of scatter appears in the results.

Of the three factors mentioned which contribute to the running costs the most dominant is the contribution from the capital charges. The cost of the shielding, containment, reactor, and the safety precautions that have to be built into the system, cause the nuclear ships capital costs for machinery to be some three to four times greater than those of conventional machinery. When one considers the rigorous approach which has to be adopted in the present state of development to guard against exposure to radiation hazards under all conditions including collision, fire, flooding, grounding, sinking, and vibration and shock this is not perhaps surprising. This contribution could in fact amount to some 60 per cent of the total operating costs as things stand today.

With regard to (ii), fuel costs should be less than for conventional fuel but not perhaps as low as one might superficially expect by the time the investment, fabrication and reprocessing charges are taken into account and they might amount to some 20 per cent of the operating costs. Doubling the life of the fuel element might lead to something like a 30 per cent reduction in fuel costs but only an 8 to 10 per cent reduction in overall costs.

When one turns to the last item, *Basic Charges*, because of such factors as increased maintenance difficulties, the necessarily complex refuelling arrangements, the need for specialized equipment such as special defuelling berths, cooling ponds, heavy shielded coffins for transport, basic health physics support and the need for at least some

Table 3. Typical operating parameters for conventional ship installations

	Specific weight (lb per s.h.p.*)	Specific fuel consumption (lb per s.h.p. per hour)	Fuel cost (pence per s.h.p. per hour)	Fuel carried for voyage (tons†)	Probable power range (s.h.p.)	General remarks
Direct drive diesel installations	300 (580)	0·35	0·3	2800	up to 25,000	Wide use, particularly for smaller powered ships, higher maintenance than for steam turbine. Approx. 160 s.h.p. per ft length of engine
Geared steam turbine installations	166 (586)‡	0·53	0·42	4200	For all marine powers above 6000	Widespread use. Highly developed. Extremely reliable. Approx. 16 to 17 cu ft machinery space per s.h.p. Cost from £70 per s.h.p. (smaller powers) to £60 per s.h.p. (for 20,000 s.h.p.).

* Fuel weights for 22,000 s.h.p. (47,000 d.w. tanker), 17 knots, 11,000 mile voyage United Kingdom to Persian Gulf
† Specific weights for steam plants for Naval vessels considerably lower; probably less than 50 lb per s.h.p.
‡ Specific weights given in brackets include fuel weight

Table 4. Comparative parameters for different reactor systems

| Reactor system	PWR Savannah type	PWR highly enriched submarine type	Calder Hall type	Slightly enriched Calder Hall (300 lb per in³, 400°C)	Enriched, gas cooled, closed-cycle gas turbine (550°C gas temperature)	Heavy-water moderated gas cooled	Enriched organic moderated and cooled
Specific weight of machinery (lb per s.h.p.)	300–350	150–200	2000	500	150–200	370	200
Shield weight as percentage of total machinery	30–35	20	55	45	40–50	40	40
Specific costs, reactor and machinery	£170 per s.h.p.	—	£250 per h.p.	£160 per h.p.	Figures approximate only. Dependent on many factors. Suitable for installations of about 20,000 s.h.p		
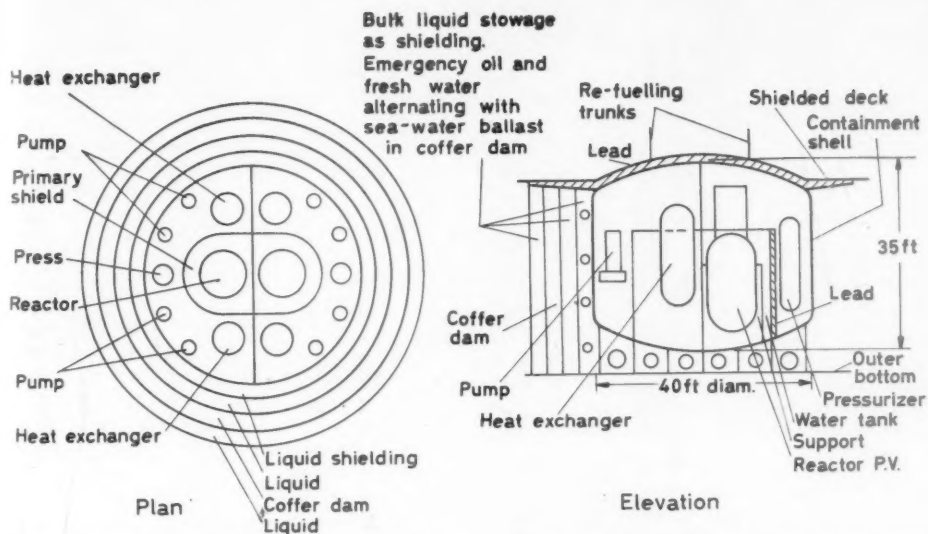
Figure 4. *Possible shielding arrangement for nuclear passenger liner shown in Figure 3. The ship is of 30,000 tons displacement, speed 24 knots, twin reactor, twin screw layout, 20,000 s.h.p./shaft. PWR reactor system with 5 ft diameter core. The pressure vessel is 9 ft diameter by 25 ft high, and the containment vessel is 40 ft diameter on the vertical axis. The primary shield (150 tons) is a radial water blanket contained in a steel tank, lead clad on the outer face. The tank acts as a support for the pressure vessel and is integrated with the hull. The secondary top shield (250 tons) is a lead/polythene deck over the containment vessel and the secondary radial shield (1500 ton liquids, 200 ton containment and 200 ton structural weight) uses the bulk liquid stowage, fuel and water in concentric tanks. Alternatively the secondary radial shield could use 6 in. lead plus 8 in. thick polythene (total 1250 tons) on the outside of the containment vessel; this is three times more expensive than the first alternative*

specialist members in the crew, it is almost certain that the basic charges will in general be higher than for conventional ships. The question of insurance rates has not yet been settled and whilst statistical analysis shows only a low probability of accident—for instance one might expect some seven accidents per year involving ships of 20,000 dwt tons or over of which only a few would occur in or near populated areas—the fact that increased capital will be locked up in nuclear ships and there will be a risk, even though it seems remote, of widespread repercussions from a serious accident, seems bound to increase insurance rates. Therefore of the three items going towards influencing the running costs of a ship, at least two are going to be greater at the present state of development than for a conventional ship and this leads to the figures produced from the analyses mentioned earlier.

The question of saving oil fuel by widespread adoption of nuclear propulsion was mentioned in the introduction. This is not as great as one might expect in the shipping field since if one considers only new tanker construction in the United Kingdom over the next five years the power requirements might amount to 3000 megawatts of

heat installed which in terms of oil consumption is equivalent to approximately 1·5 millions tons annually. Whilst there is some incentive to use fissile fuel and save fossil fuel it is not great when it is seen in its proper prospective and compared against the land power requirements where the United Kingdom might expect to import in the form of oil the equivalent of some 30 million tons by 1965, over and above any imports for motor spirit.

Most Suitable Types of Ship

The type of ship best able to make use of the advantages of lower fuel cost and offset the disadvantages of high capital cost is one which has a high load factor, *i.e.*, requires little time for loading and unloading, spends a high proportion of its time at sea and for which fuel bills are heavy. The tanker with the useage factor of about 80 per cent, particularly the larger type, therefore has the greatest prospect of early economic use of nuclear power. The fast passenger liner with its demand for high power and large fuel requirements, despite its lower time-at-sea factor might also be attractive in the long term, and, as an illustration, *Figures 3*

Table 5.   Characteristics of the United States reactor design proposals for ship propulsions, 22,000 s.h.p.

Designer	Babcock & Wilcox	American machine and Foundry (AMF)	Atomics International	General Atomic
Type	*Savannah* PWR	Boiling water	Organic moderated	Gas-cooled (CO_2) zirconium-hydride moderator
Full power core (MW, heat)	74	74·5	70	55
Endurance (F.P., h)	14,400	7600	13,500	10,800
Temperature coeff. (10^{-5} per °C)	− 50	− 11	− 12	− 1·7
Core (diameter × height)	Cylinder 61 in. × 66 in.	Cylinder 57½ in. × 60 in.	Cylinder 72 in. × 72 in.	Hexagon 68 in. × 66 in.
U 235 (kg) and Enrichment (%)	330* 4%	160 9·5%	245 1·58%	120* 28·6%
Coolant flow (10^3 lb per h)	8000	4190	10,000	1230
Primary circuit pressure (lb per in² abs)	1750	900	35	2000
Outlet temperature (°C)	271	279	328	700
Fuel element type	UO₂ pellets in stainless steel tubes, ½ in. o.d.	UO₂ pellets canned in Zircalloy 2	Plate	UO₂/stainless steel (ss) cermet clad in stainless steel, rod type
Control rods	21 cruciform silver–cadmium–indium alloy (?)	Cruciform 12B–ss/4Hf	Cylinder 16B/ss	Hexagon 25

*Plus boron as burnable poison

and *4* present a hypothetical passenger liner with a twin reactor system.

The ship illustrated (*Figure 2*) is taken to be about 30,000 tons displacement and 40,000 shp on two shafts and, as shown, makes use of the liquid stowage, *e.g.* 500 tons of emergency fuel oil and 1000 tons of fresh water in the secondary shield arranged in concentric tanks around the containment vessel. This arrangement would afford useful protection against collision. By the use of such liquid stowage and by minimizing crew time spent in the vicinity of the reactor and keeping the reactor system situated as much below the water line as possible it should be feasible in the long term to get a nuclear ship of similar speed, pay load, and amenities as its conventional counterpart on a hull displacing some 10 per cent less. *Tables 3* and *4* show typical operating parameters for conventional machinery against which the nuclear power plants would have to compete, and some comparative parameters for reactor systems.

It can be seen from *Tables 3* and *4* that on specific weight alone the nuclear system cannot compete with the geared steam turbine installation; if one includes in the specific weight figure however, the fuel that has to be carried for a typical voyage then the nuclear system becomes directly competitive on a specific weight basis, at least in the more compact types of system. It is obvious from the foregoing that there is a need to reduce substantially the capital costs involved in the nuclear plants. A compact reactor is therefore an essential requirement since, as stated earlier, from this stems direct benefits in shielding, containment, weight and overall capital costs.

Reactor Type

To achieve this small size however, the enrichment of the fuel element must go up and if one uses the uranium 235 isotope then fuel cost will inevitably rise, possibly to such an extent as to offset the savings brought about by the reduction in capital costs. It follows that such systems should be able to make use of the cheaper fuel, plutonium 239, which, from about the mid 1960s, will begin to become available in greatly increasing quantity from the land-based power station programme. Of the systems under consideration the most compact systems are likely to be those which use light

water for moderation and coolant, *i.e.*, either the pressurized water reactor or its extension the boiling water reactor. These systems moreover can have large negative temperature coefficients and are therefore stable and manoeuvrable.

Although the physics of plutonium systems are not yet completely understood it seems possible that plutonium might be used at best advantage in liquid moderated systems with a high basic negative temperature coefficient. In the longer term, it is possible that that class of reactor known as the high temperature gas cooled reactor which operates at coolant temperatures of the order of 700 to 750°C will yield a particularly compact overall plant. This system is, however, several more years removed from the two systems mentioned earlier. The gas cooled graphite moderated system of the Calder Hall type, or developments therefrom, will in general always be bulkier than comparable light water system. *Table 5* sets out the main characteristics of some of the United States reactor design proposals for ship propulsion. These proposals are all based on producing 22,000 shp.

Naval Requirements

Before leaving the question of ship propulsion it is as well to look quickly at the naval surface ship requirements since it is here that one might find the earliest economic justification for building and operating a nuclear surface vessel. The operational advantages of the nuclear surface warships are not as obvious as for submarines since no substantial decrease of vulnerability is conferred on them. Nevertheless the advantages of independence of oil supplies, fewer worries about economic ship speeds and the promise of better designs by the elimination of boiler air intakes and outlets are attractive and one might be prepared to pay an extra price to achieve them, although much lower than in the case of the submarine. In other words one is likely to require a unit which at least approaches in economic terms the commercial requirement.

The real cost of operating surface vessels in the navy are not available but they may be expected to be higher than for commercial vessels and therefore be closer to the predicted cost of nuclear operation at the moment. In terms of operational value it is of little use to apply nuclear power to a single ship, as one must in the preliminary stages of

development; if however a fast, large tanker was nuclear powered and able to serve in the fleet replenishment role it would be able in part to confer its advantage of increased bunker capacity and speed to a large proportion of the fleet.

The large submarine tanker has been frequently mentioned and this, if it is ever required, could probably only be made practicable by the use of nuclear power. It appears, however, that these tankers would show to no advantage over surface tankers until speeds above the order of 50 knots are reached and when this point is achieved it is probable that the nuclear plant, shielded only by the oil fuel carried, would be the one method of producing the power required. At such speeds it is also likely that the propellers would be replaced by a jet type of propulsion device such as the hydroduct and thus parallel aircraft development.

Conclusion

In summary, then, it can be seen that at present there is no commercial incentive to apply nuclear power to surface vessels, but there are good long term prospects of getting economic justification in the large tanker application if one can substantially reduce capital plant cost by reduced size and by the use of as simple and safe a system as possible. Fuels of long life and high burn-up and higher heat rating must be sought and to achieve these aims one must contemplate the use of enriched fuel and hence must look to the cheaper plutonium to provide this.

It is exceedingly difficult to be certain about the type of reactor system which ultimately will prove to be most suitable for ship propulsion, but in view of the need for compactness and simplicity, and bearing in mind the inherent stability of the liquid moderated systems and the desirability of using plutonium fuel, the light water reactor particularly in the boiling water form appears to be an extremely promising candidate.

The intangibles one finds associated with ship operations on nuclear power, particularly the cost of support facilities can hardly be evaluated theoretically and the fast fleet replenishment tanker with the ability to perform a useful and probably economic job appears to be the best initial stepping stone in acquiring these data. Until such a ship is built and put to sea we can expect to make few real advances in this important field of nuclear power application.

Mr A. J. C. Hall who, jointly with Mr J. G. Hayes, won the first prize in the Waverley Gold Medal Essay Competition is showing Miss M. D. Lilley some of the coloured glass patterns described in his essay (December, page 461). Mr Hall was in the United Kingdom on a business trip and delayed his return to Australia in order to be present at the Prizegiving

Sir Alexander Fleck, F.R.S., Chairman of Imperial Chemical Industries Ltd, who is the new chairman of the Scientific Advisory Board of RESEARCH.

The Scientific Advisory Board of RESEARCH

THE Scientific Advisory Board of *RESEARCH*, and of the other publications produced by Butterworths Scientific Publications, developed from a committee under the chairmanship of the late Viscount WAVERLEY which met at the Cabinet Offices, Great George Street, Westminster, early in 1947 to consider the need to expand the publication of scientific material in this country. The Board, under the inspiring guidance of Lord Waverley, produced various valuable suggestions and gave advice on many occasions; the essay competitions were started, in order to encourage the presentation of scientific information in a manner intelligible to the non-specialist.

I am very pleased to announce that, at the invitation of the Scientific Advisory Board, Sir ALEXANDER FLECK, chairman of Imperial Chemical Industries Ltd* has accepted our invitation to join the Board and become its chairman. Sir Alexander's advice will be of double benefit as he is himself a research scientist, and therefore knows what scientists both must and like to read, and he has now become one of our great industrialists and is therefore well qualified to advise on the needs of industry in a technological age. I should like, on behalf of the Scientific Advisory Board and Butterworths Publications Ltd, to take this opportunity of welcoming Sir Alexander Fleck.

J. W. WHITLOCK

The Presentation of the RESEARCH Awards

The prizes were presented to the winners of the two competitions, the Waverley Gold Medal Essay Competition and the *RESEARCH* Essay Competition for Schools, by Sir CHARLES DARWIN at a meeting held at the Royal Society of Arts on Monday, December 15th; Sir Alexander Fleck was in the chair.

The Prizegiving was preceded by an entertaining and informative short address by Lord BRABAZON of Tara who recalled some of the early days of aviation. These recollections serve as a reminder of how short is the history of modern flight and how much knowledge has been acquired by man in the last half-century.

Waverley Gold Medal Essay Competition

First Prize	Mr A. J. C. HALL and Mr J. G. HAYES
Second Prize	Mr T. R. MANLEY
Special Prize	Miss M. D. LILLEY

RESEARCH Essay Competition for Schools

First Prize	Mr ROGER RANSOME
Second Prize	Mr GLYN FLOWERDEW

* A profile of Sir Alexander Fleck was published in September, 1958 (page 365).

SURVEY

Measuring Eye Movements

Most of us have at some time or other suffered from fatigue due to having read small print for too long a period, perhaps under poor illumination. This type of fatigue occurs even more rapidly when an operator scans a radar screen or an instrument panel for a long time. One of the many small groups that is investigating the manner in which the human eye looks at things, and at what stage fatigue will in fact set in, is the Psychological Research Laboratory of E.M.I. They have developed a new method, which is both practical and elegant which utilizes the fact that the eye ball itself will act as an electrical battery when it moves.

There have been many experiments whereby a beam of light reflected by the cornea gives a measure of the movement of the eye. This method is however somewhat limited as the actual spot of light tends to introduce spurious results, and it is also limited both in accuracy and the range of eye movements that can be recorded. The equipment developed by the group at E.M.I. measures up to 30 degrees of eye movement, with an accuracy of about one to two degrees; the latter depends on the individual subject and the length of the testing period. As different people give different voltages per degree of eye movement. The accuracy can in fact only be expressed in statistical terms.

If the eye ball is considered to be carrying a positive charge near the cornea and a negative charge near the retina, then when two electrodes are placed on the temples of a subject, the movement of the eyeballs will generate a small current, corresponding to the horizontal deflection of the eye. Similarly electrodes placed above and below one eye ball will record the vertical movement. For analytical purposes the equipment uses a two-channel pen recorder to record horizontal and vertical movements separately. The current generated by a 30 degree eye movement is about 300 microvolts per eye, but due to losses, the usual galvanometer reading is rather less than this. To diminish unwanted skin voltage, the skin is lightly drilled at the points which will receive the electrodes—no bleeding occurs and no pain is felt—and the subject's head is located in the same position for each experiment using a dental positioning jig having a plastic impression of the subject's teeth.

There are many questions which should be answered. When we look at a page of print or radar screen how much can we see in a unit of time? Do we overshoot or undershoot? At what stage does fatigue set in and how does it affect what we see or think we see? The electro-ocularography equipment described is obviously a powerful research tool for until we know the answer to these questions little can be done to improve designs in order to minimize fatigue.

Ionizing Radiations for Food Preservation

The F.A.O. meeting, held at Harwell in November, discussed the present status of food irradiation, its potentialities in European countries and the need for international cooperation in future research in Europe. The delegates included representatives of seventeen European member governments, fourteen international organizations and four observers from the United States who were invited to summarize American research.

An immediate problem concerned levels of application which will control spoilage without loss in quality and nutritive value of the treated commodities. Low dose treatments appear feasible to delay sprouting in root crops, to induce reproductive sterilization of insects and to destroy certain parasites in meat; however, the consequential colour, flavour and textural changes brought about by the higher doses necessary to destroy micro-organisms are usually considered objectionable. It was suggested that the combined use of a low level of treatment and antibiotics or refrigeration, or both, was of more definite promise. Fundamental microbiological aspects and the economics of application must be further clarified before considering commercial application, which was not thought to be likely for several years.

Due to the high cost of equipment and the training of highly specialized personnel, international cooperation was stressed to promote wider research. Training and research fellowships on an international basis were suggested.   E.A.W.

BOOK REVIEWS

Concepts of Classical Optics

J. STRONG

(*xvi*+713 *pp*; 9¼ *in. by 6 in.*)
San Francisco: W. H. Freeman; London: Bailey
Bros. & Swinfen. $9.50; 80s

JOHN STRONG has done it again! Twenty years ago
he published, with the collaboration of his friends, a
book devoted to certain of the laboratory arts, *Modern
Physical Laboratory Practice* with illustrations by ROGER
HAYWARD. This book has become a classic for every
self-respecting research student knows something of it
and has derived profit from consulting it. The present
book shows reminiscent features: there are some 368
pages of text followed by some seventeen appendices
written by specialist friends and research students. These
appendices occupy a little under 300 pages, and
throughout there are the vivid helpful drawings of Roger
Hayward!

It is a fitting book to come from John Hopkins with
which R. W. WOOD and A. H. PFUND were associated
for so long. The flavour is that of the art and craft of
optics. It has evolved and grown in the author's mind
from thinking about optics not from a desire to set out a
rigorous treatise. The mathematics is what we might
term undergraduate mathematics, what the author calls
'the mathematics of modest rigor'. It is described as
being 'intended for an intermediate course in optics'.
The word intermediate is to be interpreted in the Ameri-
can not the British academic sense. It is true that in
places one hopes that an honours student will appreciate
the significance of more exhaustive treatments of some of
the topics but nowhere will he obtain a better appreciation
of the feel and range and elegance of the subject. Every-
where the emphasis is on how the experiments can be
carried out in practice.

The appendices cover a wide and miscellaneous range
of topics from applications of interferometry by Ewart
Williams to fibre optics by Kapany and microwave
experiments and their optical analogue by Hull. The
selection of topics to be developed in the appendices is
wide and a reflection of Professor Strong's interest. They
certainly blow away any cobwebs which may be in
danger of covering a reader's interests. One cannot
read for instance, the appendix on apodization by
Jacquinot without itching to make some apodizing
screens.

The Exploration of Space by Radio

R. HANBURY BROWN and A. C. B. LOVELL

(*xii*+207 *pp*; 10 *in. by 8 in.*)
London: Chapman & Hall. 35s

RADIO astronomy has grown, since the initial observation
by Jansky in 1932 of radio waves from the Milky Way, to
the stage of contributing substantially to our under-
standing of the universe. In the span of a few years
radio has become a major source of information on the
interstellar gas, on the outer atmosphere of the sun, and

on meteors, to quote a few sample topics. Because this
growth has been restricted to such a short period, in
comparison with the millenia taken by optical astronomy,
the rate of discovery tends to be very fast and perspectives
change quickly. In such circumstances review publica-
tions—survey articles, research monographs, and books
of general scientific appeal—tend to be particularly
valuable.

The authors of *The Exploration of Space by Radio*—
the director and the second-in-command at the Jodrell
Bank Experimental Station—are well equipped to make
such a review. Their book admirably fulfills the third
role; it gives an easily read outline of the whole of radio
astronomy and goes into greater detail on various aspects
in which Jodrell Bank has been specially prominent. In
particular it describes the construction and the expected
role of the huge 250-foot steerable radio telescope which
was completed at Jodrell Bank at about the same time as
the book.

Radio astronomy is a borderline subject between
radio and astronomy and fringing, in the outer terre-
strial atmosphere, on geophysics. The book includes
chapters on the astronomical background and on those
aspects of radio technique which are important in, or
peculiar to, radio astronomy. The basic chapters on
galactic and extragalactic radio emission are short but
put the subject in excellent perspective. The chapter on
meteors is relatively more detailed, reflecting the large
part which Jodrell Bank has played in meteor astronomy.
The chapter on the sun is less satisfying. Solar radio
astronomy went through a barren five year period which
now appears to have been terminated by new discoveries
and ideas following on the introduction of outstanding
new equipment. The book came at the end of the barren
period. There are also chapters on upper atmosphere
phenomena, scintillation of radio stars and the aurorae,
and on radio investigations of the moon, planets and the
earth satellite. The book is aptly dated by the fact that
the satellite described is the prospective initial U.S.A.
one and not Sputnik I which, subsequent to the writing of
the book, was located with much publicity by the Jodrell
Bank 250-foot telescope.   J. L. PAWSEY

Practical Microscopy

L. C. MARTIN and B. K. JOHNSON

(*138 pp*; 7½ *in. by 4¾ in.*)
London: Blackie. 12s 6d

MICROSCOPY now plays an extremely important role in
many research techniques, but little information is
readily available on strictly practical matters which make
the difference between fruitful use, and all too common
abuse, of microscopes. This very useful work cannot
fail to attract attention. A book of this size cannot hope,
and this one does not claim, to be a source of detailed
information on practical applications of microscopy, but
it seeks rather to acquaint the reader with basic prin-
ciples, and deals almost exclusively with the light micro-
scope. It includes a severely limited amount of theory,

enough only for a proper understanding of the terms used and the reason for some of the practice.

Thus the book opens with the definition and measurement of the magnification of objectives, eyepieces, and microscopes, and there is a chapter on the importance and measurement of numerical aperture, and its relation to useful and empty magnification. Methods of illuminating objects including those of dark ground and phase microscopy are described, and there is a useful section on photomicrography. Some information is given on the preparation of specimens, and difficulties of the interpretation of images are discussed. There are chapters on the metallurgical microscope, the polarisation microscope, and ultra-violet microscopy.

The authors make no special claims about the type of reader to whom the book is directed, and it could be argued that it touches too lightly on too many aspects of microscopy. To a research worker seeking information on the application of microscopy to his particular problems, the book may be a disappointment, but to the technician, student, and reader seeking more general information, it could be very helpful. Indeed it must have been for this last group of readers that a chapter on the electron microscope has been included—a chapter which could perhaps have been omitted.

There have been few changes in the new edition of this book. Some new plates have been used, brief mention is made of reflecting objectives and interference microscopy, and there is a list of text-books for further reference. In addition there are now two useful appendices, one on the routine procedure for adjusting a microscope, and the other containing information about light sources.

W. J. BATES

Theoretical Electromagnetism

W. R. MYERS

(xii + 274 pp; 8¾ in. by 5½ in.)
London: Butterworths Scientific Publications. 42s

THE stated aim of this work is to provide a concise introduction to the essentials of electromagnetic theory together with a few examples of its application. Chapters are devoted to electrostatics, magnetostatics, electromagnetic induction, Maxwell's equations and circuit concepts and electromagnetic waves. The production of the book is attractive and both formulae and diagrams are clearly presented. The addition of a chapter on worked examples is a valuable feature, but it is unfortunate that these are restricted to electrostatics, since magnetic problems are of greater practical importance and here the competent use of vector potential is not, as the author implies, simply a matter of extending the mathematical procedures. The scope of an elementary

text-book is naturally limited and it is only reasonable to find that relativity, for example, should be neglected. It is difficult, however, to justify the complete absence of any treatment of ferromagnetism. With these exceptions the book appears to pass the reviewer's first test, namely whether a student who had studied it seriously would be adequately informed.

This simple test is unfortunately not the only one which must be applied. For electromagnetism is a unique subject in that its fundamentals appear for many years to have caused almost complete confusion to both student and graduate alike. This confusion follows from the adoption of an irrational approach and the introduction of philosophical discussions in an attempt to justify it. In the reviewer's opinion the present book, like many others, fails badly on both counts. The fact that electricity and magnetism are not independent subjects but different aspects of one electromagnetism has been established for almost a century, and it is quite amazing that the inadequate historical two-axis approach should still be reproduced. Matters are made very much worse when an attempt is made to fit this irrational approach to rationalized M.K.S. units simply by manipulations with a $4\pi\varepsilon$ here and a $4\pi\mu$ there. Units clearly possess no intrinsic merit of their own, but only merit with respect to the approach adopted. For the historic approach to electrostatics through Coulomb's law, the c.g.s. e.s.u. system of units is the only natural one. For if this is really to be considered as the first experimental result in electromagnetism, then clearly it must be presented in its simplest possible form $F = q_1q_2/r^2$ with only one new concept, that of charge. To start with Coulomb's law in the form $F = q_1q_2r/4\pi\varepsilon r^3$, as is done on page 8 of the text, where ε has the units of farads/metre and the concept of capacitance is unknown, is to the reviewer, as ridiculous as writing say Ohm's law in the form $V = (R/4\pi\varepsilon).I$. It is however a simple matter with a different approach to deduce Coulomb's law in this form.

The author seems to sense the difficulties, but instead of abandoning the historical approach prefers to present it with a philosophical justification. Experience shows that whilst designed to clarify, this process in fact deepens the confusion. The same is true of the familiar table of units, dimensions and conversion factors given in *Appendix 4*. Whilst to the experienced reader the reminder that ohmic resistance has the dimensions of m.p.h. in the e.m. system and hours/mile in the e.s. system—with the fascinating corollary that the ratio of one ohm to another has the dimensions of velocity squared—is just amusing, and it can only confuse and undermine the confidence of the serious student.

C. V. JONES

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